HANNOVER

ON

THE MICROSCOPE.

ON

THE CONSTRUCTION AND USE

OF

THE MICROSCOPE.

BY

ADOLPHE HANNOVER, M.D.,
LECTURER ON ANATOMY IN THE UNIVERSITY OF COPENHAGEN.

EDITED BY

JOHN GOODSIR, F.R.S.E.,
PROFESSOR OF ANATOMY IN THE UNIVERSITY OF EDINBURGH.

EDINBURGH:
SUTHERLAND AND KNOX, GEORGE STREET.
LONDON: SIMPKIN, MARSHALL, AND CO.

MDCCCLIII.

MURRAY AND GIBB, PRINTERS, EDINBURGH.

PREFATORY NOTE.

The supervision of the English edition of Dr Hannover's Work on the Microscope was undertaken at his own request—and I have to regret that the little leisure at my command has delayed publication so long.

Dr Hannover's Treatise is highly esteemed on the Continent, and I have no doubt that its appearance in an English form will be duly appreciated by the increasing class in this country engaged in microscopical investigation.

JOHN GOODSIR.

University, Edinburgh,
March 9, 1853.

PREFACE.

It is my desire that the present Volume may serve as a guide, not only for those who already possess a microscope, and have had some practice in microscopical observations, but also for those who have only occasional opportunities of employing such an instrument, and who must, therefore, content themselves for the most part with mere delineations or descriptions of microscopical objects; for although the frequent use of the microscope is the best guide to its management, written instructions are frequently of service either in giving rules and indicating manipulations, which might otherwise escape the attention of the observer, or by sparing him the time and trouble that experience in general costs. I have, moreover, not unfrequently had occasion to remark, however singular it may appear, that those even who understand the practical use of the microscope are deficient in a theoretical knowledge of the instrument, and are unacquainted with the principles that regulate its construction. I would hope that the present work may prove acceptable to that more numerous class of persons who do not themselves take part in microscopical investigations, and who must, therefore, rest satisfied with mere delineations and descriptions. Such persons may possibly derive benefit from the practical, not less than the theoretical, portion of the book, since they will be the better able to esti-

mate the correctness of a microscopical observation, when they have learnt the manner in which it has been made, and understand the difficulties by which it has been attended, and the methods by which they were overcome. I would also hope that my work may not be wholly devoid of interest even to those persons who are not especially engaged either in natural or medical science, since it affords information in reference to an instrument so extensively employed, and which may not only be regarded as indispensable to every one who occupies himself with any branch of natural science, but admits not unfrequently of being applied to the affairs of ordinary life.

These motives have induced me to give the book a more popular form, as well as to make it as practically useful as possible. The theoretical portion, therefore, only contains the principles of Dioptrics and Catoptrics, without which the construction of the microscope could not be understood; and the section treating of these subjects is further limited to the explanation of the apparatus used at the present time, although I have appended, for the sake of completeness, an historical sketch of the manner in which each part of the microscope is constructed and arranged. The instructions for the use of the microscope are given with the greatest fulness, as constituting the most important section of the work; and as the dioptric compound microscope is the one most used at present, I have limited my observations to that alone.

In conformity with this arrangement I considered it superfluous to give a detailed description of instruments and apparatus which have become obsolete, and are solely valuable, in a technical point of view, to those who prepare them. or who may be desirous, by help of test-objects or otherwise. to try the chromatic and spherical aberration of the lenses. their incorrect centring, the defining and penetrating power of the microscope, the angle of the aperture of the object-

piece, and its distance from the object, etc. Great practice is, moreover, necessary for conducting such an examination. I have, for a similar reason, abstained from giving any opinion of the microscopes of different instrument makers. Microscopes may be obtained at various prices, and so much industry and care are applied by most of those who construct these instruments (Schiek, Plössl, Chevalier, Oberhäuser, Brunner, Pritchard, Amici, etc.), that it is difficult to say which are the best. Whilst one microscope deserves the preference for the mechanical action of the different parts, another is more highly esteemed for its optical arrangements; again, one microscope may be more serviceable than another for transparent or opaque bodies, or an observer, from partiality, may wish the mechanical or optical composition of his microscope arranged for some one special mode of investigation. Besides this, on giving advice concerning the choice of a microscope, one is induced from predilection for instruments of some particular maker, to recommend the kind which one is in the habit of using. Daily practice with the same instrument necessarily leads one to overlook or become accustomed to defects whose influence one learns to counteract. That microscope is the best which shows objects more distinctly with a weak magnifying power than other instruments with higher powers, and in which any kind of object is seen most clearly. When the instrument is not absolutely bad, its relative goodness is of less importance than the powers of vision of the observer. Leeuwenhoeck's microscopical researches, which were conducted with instruments which, according to our views, were highly defective, are a singular illustration of what can be accomplished by a penetrating and unfettered eye, notwithstanding such obstacles.

The first of the plates gives only the most necessary or commonly used apparatus, without wishing to indicate that all the instruments delineated are indispensable. But this

will be made evident by the descriptions given of them. On the other plate will be found models of the microscope in most frequent use at the present time.

Should this work contribute towards bringing an instrument into more extensive use, for which, I believe, in the course of my earlier efforts I have excited some interest amongst my countrymen, the object contemplated by its publication will be fully attained.

THE AUTHOR.

COPENHAGEN.

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TO THE BINDER.

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PRELIMINARY REMARKS.

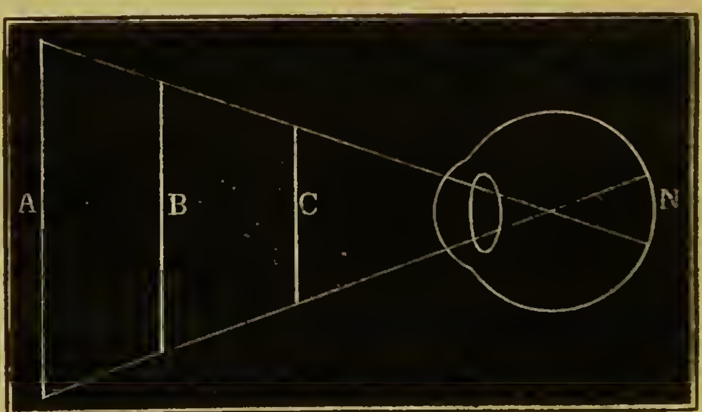
An object is only distinctly seen by the eye, when a distinct image of it is formed upon the retina. In order that such may be the case, each of the pencils of rays emitted from the several points of the object must be again collected in as many corresponding points upon the retina; if the pencils of rays be collected either before or behind it, the image on the retina, as well as the object, becomes indistinct. As long as the object is at a great distance, the rays emitted from it must be considered as parallel, and the pencils of rays behind the lens of the eye will intersect one another on the retina. But if the object be brought nearer, and the rays proceeding from it consequently become divergent, the eye and its refracting media must be adapted in such a manner to the varying distance of the object, that a distinct image of it shall fall precisely upon the retina itself. The power of adaptation, however, has certain limits, especially for proximate small objects; and there is a fitting distance from the eye at which smaller objects, when illuminated in an ordinary degree, may be placed without becoming indistinct. This distance is called the *distance of distinct vision.*

The distance of distinct vision varies in different individuals. A sound eye can, in general, read print of ordinary size at a distance of from eight to ten inches; a short-sighted person may, on the other hand, bring a book very much nearer to the eye, without loss of distinctness; for the transparent parts of his eye possess a stronger refracting power, and are able to collect the strongly divergent rays which are the cause of the indistinctness of vision experienced by a long-sighted person, when the object is brought too

near to the eye. At the same time, a long-sighted person can place the object at a greater distance from the eye, without its becoming indistinct; for the transparent parts of his eye possess a weaker refracting power, and can only collect the parallel or slightly divergent rays emitted from a more distant object. This variety in the eyes of different individuals is the cause of the differences in the distance of distinct vision. This distance has been fixed by Brewster at five, but by others at fifteen inches. The usual distance is, however, as already mentioned, from eight to ten inches. As we shall presently see, the determination of this distance is of great importance in micrometry. In microscopical investigations, we will follow the French optician (Charles Chevalier) in reckoning the distance of distinct vision at twenty-five centimetres (which is about ten inches). This measurement deserves the preference from its decimal character, when we make use of the convenient metrical division; but a great want of uniformity prevails in the determination of microscopical magnitudes as in all other numerical determinations of ordinary life.

We form an opinion of the magnitude of an object from the angle which is formed by the rays of light emitted from its extreme points, when they intersect each other behind the lens of the eye. This angle is called the *visual angle*. All objects which are seen at the same visual angle appear of the same magnitude. Thus the objects A, B, C, appear to us to be of equal size, because

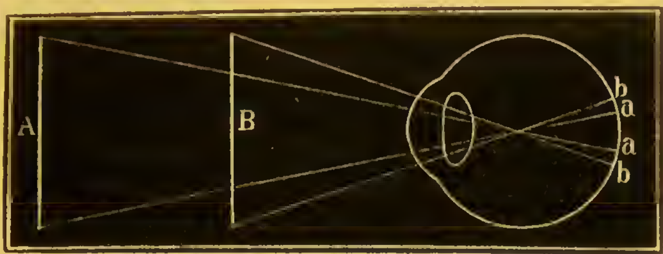
Fig. 1.



the visual angle is the same, and the space which the image occupies upon the retina N remains unchanged, whilst the distances

of the objects are different, and the objects themselves are of unequal size. If we look at the same object from different distances, it will appear larger or smaller, according to its greater or lesser proximity to the eye. This also depends upon the size of the visual angle.

Fig. 2.



If, for example, we look at the line A, we judge of its magnitude by that of its image on the retina, *a a*, or by the angle subtended by the arc, and opposite to the visual angle; if we wish to see the object enlarged under the same illumination, we bring it nearer to the eye at B; for then the visual angle becomes larger, and consequently the image on the retina, *b b*, becomes larger than *a a*. The apparent magnitude of two lines is, therefore, in an inverse proportion to their distances from the eye; and as a plane has extension in two directions, the apparent extent of two equal planes is in an inverse proportion to the squares of their distances.

From the above remarks, it would appear as if we had the power of seeing objects enlarged by continuing to bring them nearer to the eye; but here we meet with a limit. For if the object approach the eye too closely, or, in other words, come considerably within the limits of distinct vision, it becomes indistinct, on account of the too great divergence of the rays of light. A short-sighted person can, however, collect these rays, and may, consequently, obtain a distinct image, which at the same time appears larger to him than it would to a long-sighted person; the former, therefore, sees small objects better than the latter. Now what holds for the image formed by the naked eye only is equally applicable to the image formed by the assistance of magnifying instruments. To a short-sighted person, whose distance of distinct vision is only five inches, a given enlargement will appear less than it does to a long-sighted person.

In order to see an object in a magnified state, without its distinct-

ness becoming impaired by bringing it too near to the eye, we render the eye short-sighted, as it were, by causing the rays that are too divergent to become parallel, or nearly so. One of the methods by which this is effected we learn from nature, when we consider the structure of the eye. We place between our eye and the object a transparent body, the surfaces of which possess the property of changing the direction of the rays of light, so that divergent or parallel rays become convergent. Such a body is called a *lens;* however, we also include in this term such bodies as can cause convergent or parallel rays to become divergent. Lenses are distinguished according to their various surfaces as follows:—

Fig. 3.

A B C D E F

A, double convex, B, double concave,—the surfaces may be portions of spheres having the same, or different radii; C, plano-convex, with a plane and a convex surface; D, plano-concave, with a plane and a concave surface; E, concavo-convex, with a concave and a convex surface, which surfaces either never intersect each other, to whatever distance they may be continued, or they are periscopic, F, forming a meniscus, with a concave and a convex surface, but which meet each other when continued. A section of one of these last-named lenses is therefore crescent-shaped.

In the following pages, our attention will chiefly be directed to lenses of glass, that being the material of which they are usually made. In order to understand the *refraction* of rays of light, which is the subject of dioptrics, it is necessary first to examine their refraction by transparent bodies having plane surfaces.

As long as a ray of light continues in the same medium, it pursues its course uninterruptedly in a straight line. If it meet the surface of a transparent body at a right angle, it still proceeds in the same direction. If, on the contrary, it meet the surface at any other angle, it will be refracted. The same takes place, whether

the new body present a plane or a curved surface; for, in the latter case, the direction will be determined by the tangent, which is perpendicular to the radius of the curved surface. The direction in which the ray of light will continue its course depends upon the density of the bodies. When rays pass from a rarer to a denser medium, they approach the ray which may be imagined perpendicular to the new medium; when they proceed from a denser to a rarer medium, they recede from the perpendicular ray. If, for example, the oblique ray AB passes from the air through a glass

Fig. 4.

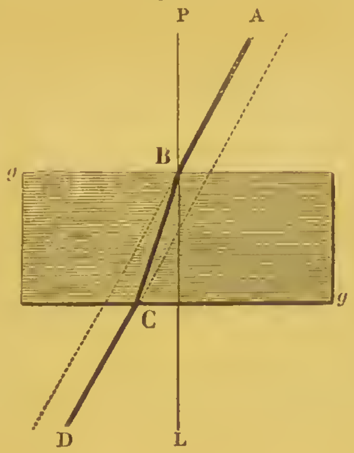
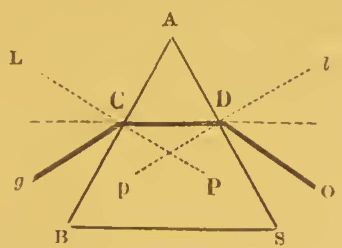


plate *gg*, it will approach the perpendicular line PL and take the direction BC; if, again, it passes from the denser medium, the glass, into the air, it will recede from the perpendicular line and take the direction CD. If the surfaces of the glass *gg* be parallel, CD also becomes parallel to AB, or the refracted ray of light will continue its course in a direction which is parallel with the incident ray. If, on the contrary, the surfaces be not parallel, the parallelism of the

Fig. 5.

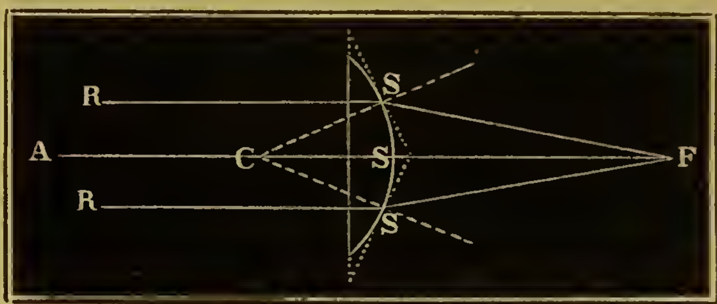


incident and the refracted part of the ray ceases. This, for example, takes place in the passage of rays through a triangular prism.

If the ray *g*C fall obliquely upon the surface AB, it approaches LP, which is perpendicular to AB, and takes the direction CD; but passing from the prism into the air, it recedes from *lp*, which is perpendicular to AS, and takes the direction DO, which is not parallel with the direction of the incident ray *g*C. Hence it follows, that when the eye is placed at O, it will see the object *g* in the direction OD. The two surfaces AB and AS, through which the rays pass, form the *refracting angle* A, and the opposite side BS forms the *base of the prism.*

The refraction of rays of light through a lens follows the same laws as the refraction through a triangular prism. We will consider the simplest case, when parallel rays of light fall perpendicularly on the plane surface of a plano-convex lens, whose con

Fig. 6.



vexity is a segment of a sphere with the radius CS. The rays RS, AS and RS pass in the same parallel direction through the lens, until they reach the convex surface. The ray AS is called the *axial ray*, because it passes through the *axis of the lens*, or the line which may be imagined to be drawn through the centres of the two surfaces of the lens. As the radius CS is perpendicular to the tangent, this ray proceeds uninterruptedly in the same direction to F. The marginal rays RS and RS cease to be parallel as in the prism, and are refracted at the same time from the perpendicular, which is the radius CS. They converge to the point F. This point, where the parallel rays are collected, is called the *focus of the lens.* In a plano-convex lens, the *optical centre of the lens* is situated at the point where the axial ray meets the convex surface; in a double convex lens, it is situated within the lens at its very centre, when the surfaces have equal convexity. The distance from the focus to the optical centre is called the *focal distance of the lens:* its magnitude

depends on the material of the lenses and the curvature of the surfaces; the greater the refracting power of the material, and the greater the curvature of the surfaces, the shorter will be the focal distance of a convex lens.

The passage of different rays through a double convex lens, will be clearly understood by the following figure. If the rays P, A, P,

Fig. 7.

which are parallel to each other and to the axis of the lens, pass through a double convex lens, they will be refracted by both convex surfaces, and then collected in the focus F. If the rays D, D diverge upon the lens, they will meet on the other side of it in the point D′, which lies beyond the focus. The nearer the lens is to the point from which the rays issue, the farther will the point be at which the rays collect on the other side of the lens, and if this point be in the focus of the lens, the rays become parallel and therefore never meet; *lastly*, they become divergent, when their point of divergence lies between the lens and its focus. If the rays C, C finally become convergent, they will unite in a point C′ between the lens and its focus. The greater the distance of the point is from the lens, at which the incident rays would meet if produced backwards, the nearer will their point of convergence be to the focus of the lens; for their divergence approaches more and more the direction of the parallel rays; and this point will ultimately correspond with the focus of the lens.

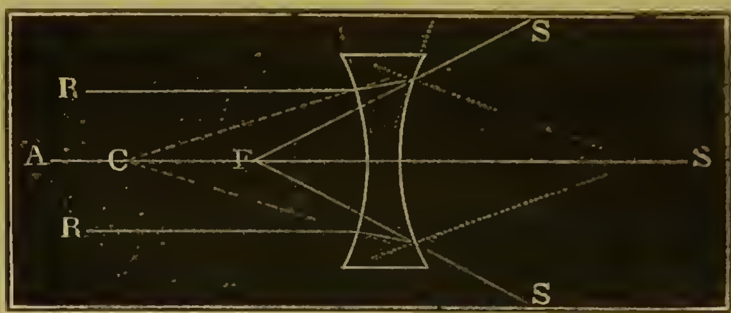
If the rays which pass through a double convex lens be parallel, although they fall obliquely upon the axial ray, they will be united at points lying in the same direction as the axial ray of the oblique rays.

Refraction by spheres takes place in exactly the same manner as

with double convex lenses, having surfaces of the same curvature, only the refraction is stronger, and the focus is therefore nearer the sphere. The refractive power may be so strong that the focus may be brought within the lens itself; this is the case with a sphere of diamond, which is, therefore, useless in magnifying bodies.

Concave lenses follow the same laws as the convex; but the direction of the rays is here directly opposite. If the rays R, R be

Fig. 8.



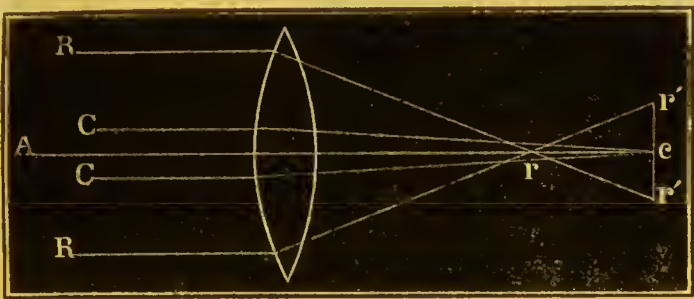
parallel to each other and to the axial ray AS, they will diverge; the axial ray AS, which corresponds to the radius of the curve, whose centre is in C, passes through the lens without being refracted. The rays issuing from R, R are first refracted towards the radius perpendicular to the tangent, but on emerging they are refracted from the radius perpendicular to the tangent of the other curvature of the lens, which is here equal to the first, and they finally converge to S, S. The point F is called the *imaginary or negative focus;* it is the point at which the divergent rays unite, if prolonged in the opposite direction. If divergent rays fall upon a concave lens, their divergence will increase after their passage through the lens; the same will take place with convergent rays, but they will diverge less on the other side of the lens.

Thus the chief properties of convex lenses are to collect rays of light, those of concave lenses to disperse them. A concavo-convex and a periscopic lens act as a concave or convex lens, according to whether the concave or the convex surface has the greater curvature.

Before we proceed further, we must notice certain defects in lenses, as, for instance, the so-called spherical and chromatic aberrations. All the rays are not equally refracted through different parts of the lens, as we have assumed to be the case generally in the fore-

going remarks; but the rays which are nearer the axial ray, or the *central rays*, are less refracted than those which impinge nearer to the edges of the lens, or the *marginal rays;* the rays, therefore, are collected in different foci, and the object, or its image, appears confused. This deviation of the rays from the principal focus is termed

Fig. 9.



spherical aberration. As will be seen, the central rays, C, C, are collected at c; the marginal rays, R, R, at r. The distance, r c, on the axial ray, A c, is called the *longitudinal aberration;* the distance, r′ r′, which comprises the intersection of the marginal rays in a plane perpendicular to the axial ray, is called the *lateral aberration.* The spherical aberration increases with the convexity of the lens; it is also greater when the surfaces of the lens are equally curved, but it is less when they are unequally curved, or when one surface is plane or elliptical; it is, therefore, also less in periscopic lenses. The most favourable ratio is where the radii of curvature are as 1 to 6. The spherical aberration is prevented by excluding the marginal rays; this is done by covering the edges of the lens with an opaque plate, perforated in its centre with a circular aperture, a *diaphragm.* The advantage thus obtained is, that the object, or its image, is seen more distinctly; but the image is less illuminated, because fewer rays of light can pass through the lens. The spherical aberration may also be considerably diminished by placing several lenses on the same axis.

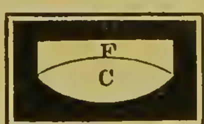
The light of the sun, as is well known, is not homogeneous, but composed of different kinds of light, each having its proper colour, —namely, violet, indigo, blue, green, yellow, orange, and red. Light is separated in its passage through a refracting body into these component parts; but in consequence of each colour differing in refrangibility, the red rays, which are least refracted,

will be collected at R, and therefore at a greater distance from the lens than the violet rays, which are those most strongly refracted, and

Fig. 10.

which, therefore, are sooner collected at V. The distance between V and R in the axis of the pencil is called the *chromatic aberration;* all the other coloured rays are collected in various points between V and R; and when, therefore, an object, or its image, intervenes between the points of union of the violet and red rays, it will be seen surrounded by rays of various colours, according as it is nearer to or more distant from the points of union of these two colours. It will appear almost colourless when at the point of intersection of the red and violet rays, or at F K, which is the *least circle of chromatic dispersion* of the lens; this is the base of a cone of colours, whose apex is at R. If the spherical aberration be considerable, the chromatic dispersion is increased at the same time, and in proportion to the convexity of the lens. This defect may be partially obviated, by causing the rays of light to pass at once through a double convex and double concave lens, by which means the rays converging from the former upon the latter are made again to diverge, and in this manner are corrected. The readiest method of effecting this is by combining two lenses, formed of materials of different refractive and dispersive powers. For this purpose two different kinds of glass are employed,—

Fig. 11.



the harder crown-glass for the double convex lens C; and flint-glass, which is softer (on account of the large quantity of lead it contains)

for the plano-concave, or the double concave lens F. The two lenses are generally cemented by means of turpentine, or Canada balsam ; a space is sometimes left between them (dialytic lenses). Two lenses thus combined are *achromatic ;* and *achromatism*, or the destruction of the dispersion of colours, is an indispensable requirement for good lenses. No attempt hitherto made to correct chromatic aberration with a single lens has as yet proved completely successful.

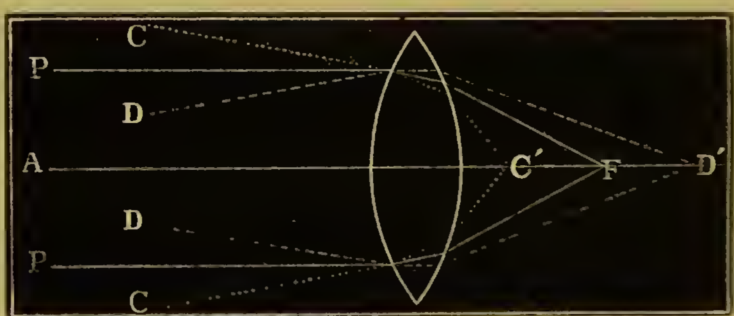
After these preliminary remarks, we proceed to the consideration of the employment of convex lenses, for magnifying an object or its image.

CHAPTER I.

ON THE SIMPLE MICROSCOPE.

WE have seen in the foregoing pages, that the nearer an object approaches the eye, the larger it appears, because the angle of vision becomes greater; but we have also remarked that there is a limit to this approximation of an object to the eye, which is determined by the distance of distinct vision. Thus, whilst the angle of vision becomes enlarged by the object being brought nearer to the eye, the excessive divergence of the rays emitted from the object is the cause of its being seen indistinctly, and it is only when the rays that issue from every point of the object are parallel, or only very slightly divergent, that the eye is able to collect them into an image upon the retina. This may be effected, by bringing a convex lens between the eye and the closely approximated object. Thus, when we

Fig. 12.



examine Fig. 12, we see that the rays issuing from F, after passing through the lens, become parallel; and therefore, if an object be placed at F, or between F and C′, but nearer F than C′, an image may be formed upon the retina by the parallel or but slightly divergent rays. But we may also see the object at a greater visual angle by the interposition of a lens. For example, an object

A B will not be seen, because it is too far distant, or, in other words, because the angle of vision is so small that the image makes no sensible impression on the retina; but if we place the lens

Fig. 13.

between the eye and the object, at such a distance that the rays, which before were too divergent, now become parallel, or but slightly divergent,—*i. e.*, if the object be brought in the focus F of the lens, or a little on the inner side of it at A′ B′, it is evident that the angle D C E must be greater than the angle A C B, and that the object will be seen in the direction C D and C E, or at a greater angle of vision, and at the same time at such a visual distance that it would not be seen without the intervention of the lens.[1] The object will appear to us so much the larger, as the angle D C E is greater than the angle A C B, or so much the larger as the distance from A′ B′ to C′, or the focal distance of the lens is within the normal distance of vision of ten inches. The magnifying power of the lens is therefore obtained by dividing the distance of distinct vision by the focal distance; the less the divisor, or the smaller the focal distance is, the greater will be the quotient, or the magnifying power of the lens. The more convex lens, which has a shorter focal distance, magnifies likewise in a greater degree.

The greater the size of the lens, the more numerous are the rays of light that can pass through it; therefore a more extensive, as well as a more luminous surface is seen through a large lens. The illuminating power of two lenses is in proportion to the squares

[1] The smallest visual angle at which an object is visible is assumed to be from half a minute to a minute; but in this case it is not merely the form of the object, but more particularly the degree of illumination, and the ground on which the object is seen, which must be taken into consideration.

of their breadths; but as the marginal rays must be excluded, on account of spherical aberration, it is necessary to limit *the field of view*, or the surface which the eye is able to see at one time through the lens by a diaphragm. The goodness of a lens very greatly depends upon the removal of the spherical aberration, in combination with a proper limitation of the field of view, which diminishes the illuminating power. The usual material of which a lens is made is *glass*. This must be perfectly homogeneous, without bubbles or striæ, completely transparent, and colourless. Such convex glass lenses may be formed either by melting or by grinding.

As early as two centuries ago, Hooke (1656) and Hartsoeker (1674) cast small balls of glass from a fine glass thread, and fastened them between two plates of lead; Della Torre cast glass balls by the help of the blowpipe; Butterfield used fine pulverised glass, which he held in the light upon a needle; Sivright cast the ball in the aperture of a platinum plate, by which means it was simultaneously enclosed in a frame. Even in more modern times, this manner of making lenses has found adherents: Lebaillif cast glass balls from fine glass bars; whilst Harting (1840) followed Sivright's method. But with balls of glass, the spherical aberration is always more considerable; it can indeed be diminished by a diaphragm, but the aperture then becomes so small that the eye can embrace only a very minute portion of the object, which, moreover, is not sufficiently illuminated, and is altogether too near to the lens. Lenses have also been made of other substances; thus Stephen Gray remarked, that the specks, which are found in glass balls, were considerably magnified when he held the ball close to his eye; and he therefore conceived the idea of boring a small hole in a metal plate, into which he introduced a drop of water, containing animalcules, and on the drop assuming a spherical form the animalcules became magnified. Hooke followed the same idea, when he brought a glass lens in contact with a fluid, and thus obtained a lens formed by the combination of a solid and a fluid body. Brewster (1837) was probably induced by these attempts to apply other fluids having a higher refractive power than water,—such as sulphuric acid, castor oil, or especially turpentine and Canada balsam,—which he allowed to dry in drops on one or on both sides of a glass plate. These lenses could be preserved a whole year. He also made use of the crystalline lenses of bleaks (*Cyprinus alburnus*), and of other

small fishes. Alcohol and volatile oils, although they refract light powerfully, cannot be used in consequence of their volatility. The inappropriateness of these materials is, however, self-evident.

Precious stones are admirably adapted for ground lenses. Brewster caused two lenses to be prepared from a ruby and a garnet, and in the year 1813 endeavoured to have diamond lenses ground; he could find no one who would undertake to grind them, until Pritchard (1826), under Goring's guidance, completed the first diamond lens, of a focal length of less than a millimetre. The advantages of these lenses consist in their greater refracting power, their nearly perfect achromatism, and their diminished aberration of sphericity. This aberration is always greater in proportion to the increased convexity of the lens, and as the diamond refracts light in an extraordinarily powerful degree, the same result can be produced by a diamond whose convexity is less than half that of a glass lens. The field of view may therefore be extended, at the same time that the distance of the lens from the object is also increased. However, diamond lenses have not realised the expectations that were formed of them; for the crystallisation of the diamond, its double refraction and polarisation, the mechanical difficulties presented, more particularly in reference to its polishing and its costliness, oppose such serious impediments to its use, that diamond lenses have not become general; neither have they been the means of leading to any discovery that could not have been observed by means of any good compound microscope. Further, the use of a single powerful lens strains the eye in a high degree; the field of view is too small, and the distance from the object, when the lens is very strong, becomes so short that the lens almost rests upon it. A lens of precious stone may indeed be preferable to a glass lens, which is also more exposed to injury; but it possesses no advantage over a compound microscope. If zirconium, sapphires, topazes, or other stones having the property of double refraction, be used, they must be cut in such a manner that the axis of the lens coincides with the axis of double refraction. Brewster considers garnets better than rubies.

Spherical lenses (*lentilles œil d'oiseau*), the idea of which was first suggested by Brewster, and afterwards modified by Coddington, are of peculiar forms (Pl. I., Fig 1). They are glass spheres, of from about a quarter of an inch to half an inch in diameter, and are ground in a plane perpendicular to any one of their axes, so that

the sides are hollowed out towards the centre of the sphere, or are furnished with a deep groove, in which a diaphragm is placed to exclude the marginal rays. Such lenses show objects with great distinctness; but here also the field of view is very small, and the focal length of the lens too short. An attempt has been made to obviate these defects by giving the surfaces of the cylinder different and slighter curvatures, and by extending the field of view by means of a larger aperture in the diaphragm; but as a consequence of this, the spherical aberration also increases. On the other hand, the convexity of the lens has been made so great (Stanhope), that its focus coincides with the surface of the lens,—and hence it is necessary to attach the object to the lens, and to hold it up towards the light on viewing it. These lenses are on the whole not much used; although they possess the advantage, that they can be immersed in water without injury, as they consist of one glass only. The above-mentioned defects are obviated in a great degree by the use of *doublets.* Wollaston first constructed, in 1812, a periscopic doublet, consisting of two plano-convex lenses of equal curvature, which were joined on their plane surfaces, but yet separated by a diaphragm, the aperture of which composed about one-fifth of the focal length of the doublet. This doublet, however, has the defect of acting as a bi-convex lens, in which the chromatic and spherical aberration is always greater than in one of a plano-convex form. The microscopic doublet which Wollaston constructed in 1828 is better. This instrument resembles two thimbles, one inserted in the other, and having a plano-convex lens, with the plane surface towards the object to be observed introduced into each thimble. If the convex surface were turned towards the object, it would more easily become soiled or otherwise injured. The focal length of the lenses is in the ratio of 3 to 1; the more powerful lens is turned towards the object. Pritchard altered the distance between the lenses. As the thickness of the doublet and the short focal length were impediments in dissecting under the lens, whilst the spherical and chromatic aberration was almost entirely removed, Charles Chevalier constructed another doublet, consisting of two plano-convex lenses of equal strength, but of unequal size, having the plane surfaces likewise turned towards the object, and separated by a diaphragm; the larger lens is the one nearest the object (Pl. I., Fig. 2). I prefer this doublet to all others. The whole doublet, which is not so thick

as those of Wollaston, allows of the passage of more rays of light, and there is sufficient space between the lens and the object. Chevalier makes them of different focal lengths; he likewise places a concave achromatic lens above the doublet to increase the distance between the lens and the object, in making use of a higher magnifying power. Pritchard has prepared triplets on the same principle as the doublets; the upper lens is the weakest, but the centering of the lenses is very difficult. The older lenses of Wilson and Fraunhofer may also be considered as doublets; they consist of two plano-convex lenses, which are adjusted in a tube at various distances, with the convex surfaces turned towards each other. Wilson's lens is still frequently used (Pl. I., Fig. 3). A combination of several of these kinds of lenses is called a *system of lenses;* the advantage obtained by them is, as formerly mentioned, that the field of view and the focal length do not decrease, although the amplification becomes greater, whilst achromatism is at the same time produced. If the combination be such that not only the chromatic, but also the spherical aberration be (as far as possible) removed, the system of lenses is called *aplanatic.* An object seen by this system appears entirely free from rings, whilst it is also very clear, and bounded by a sharp contour. The lens is usually inserted in a ring or small tube of wood, horn, metal, &c., of various forms, with or without a handle. The use of the lens is too well known to require further notice. It is best to have several lenses of various powers; those magnifying from 20 to 30 diameters will usually be sufficient. If we wish to have a higher magnifying power, it is better to have recourse to the compound microscope, unless the object be of such a nature as not to admit of its being brought under the microscope; as, for instance, in the observation of diseases of the skin or the eye in a living human being; but in such cases very high magnifying powers will rarely be required. The nearer the lens is held to the eye, the larger will be the field of view; the greater the distance, the smaller will be the field of view; for in this case the marginal rays cannot reach the eye,—and hence the practical rule to hold the lens as near the eye as possible, when we wish to see a large portion of the object. Near-sighted persons must bring the object somewhat nearer to the lens than its focus,—so that the rays may be more divergent when they reach the eye; for long-sighted persons the contrary holds good. Plano-convex lenses

are preferable to double convex glasses, because the chromatic and spherical aberration is less, and the field of view greater. In the case of these lenses, it is best to turn the plane surface towards the object, because the magnification and the field of view are both increased when we look perpendicularly through the lens. If the convex surface be turned towards the object, the magnification is smaller. The field of view is less when we look perpendicularly through the lens, but becomes enlarged in the foregoing case when we look obliquely through its margin.

The lens is commonly held in the hand, or is fastened before the eye with a ribbon tied round the head, or is pressed in between the eyeball and the bones of the orbit; but this method is trying to the eye, and prevents the escape of vapour. It is more convenient to fasten the lens upon a stand, that the hands may be free to prepare the object under observation. A lens thus fastened upon a stand forms the *single* or *simple microscope* (*microscopium simplex*).[1]

The most simple stand is a ring, fastened upon a horizontal rod, in which the lens may be inserted; it is most convenient for the ring to be attached to the rod by a socket, that it may be turned in all directions. The horizontal rod, again, is fastened either by a clamp or a screw to a perpendicular rod, upon which it can freely move up and down. The stand must rest upon a heavy pedestal, to prevent its being easily overturned; it may also be attached to a large plate, which may serve at the same time as a stage, whereon the object can be prepared.

If, however, the lens magnify more powerfully, and if, consequently, the focal length be small, the movement of the lens or of the objects upon the stand, must be regulated with more precision. This is done by applying a rack and pinion to the pillar which supports the lens or the stage, or to both. When high magnifying powers are employed, it also becomes necessary to change the mode of illumination; for ordinary day-light is then insufficient, and must be increased by a reflecting mirror placed under the stage. It was Leeuwenhoek who first applied the reflecting mirror (1668). In his

[1] The word *microscope* was first used by Demisiano; microscopes were likewise called in ancient times *conspicilia*, *muscaria*, *pulicaria*, *smicroscopia*, *engoscopia* (from ἐγγὺς near, and σκοπέω I see): Dr Goring has wished to revive the last appellation

numerous investigations he used double convex lenses of very small sizes, which were placed between two perforated metal plates; the object was fastened upon a pin, which, by means of a screw, could be moved in all directions, and every instrument was specially applicable to one or two objects. The object was held up against the light, and this plan was also pursued by later observers. Thus Wilson (1702) used a microscope consisting of two tubes, one of which was inserted in the other; to each end there was applied a lens, one of which served for magnifying, the other for the condensation of rays of light upon the object, which was placed between both, and was held fast by the aid of a spiral spring, and was examined by holding it up against the light. Lieberkühn fastened the lens in a short tube of brass in the centre of a concave and polished silver mirror; in the other end of the tube there was also a condensing lens, which threw the light upon the mirror and thence upon the object, which was fastened between both lenses. Similar microscopes were employed by Swammerdam, Lyonnet, Ellis, Cuff, and others, but they are now out of use.

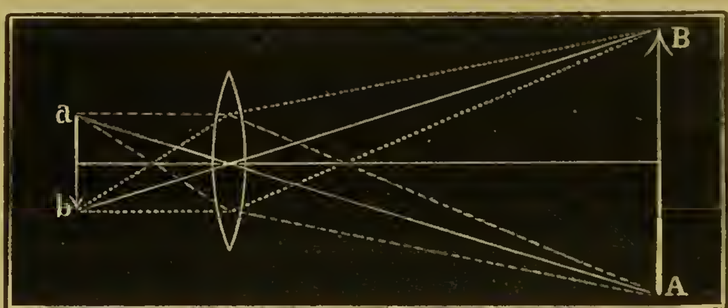
We shall have occasion to mention more circumstantially the various arrangements for illumination, together with the stage and its movement, when we treat of the compound microscope, for the principles of their application and employment are the same; indeed, certain forms of compound microscopes can, in a few moments, be changed into single microscopes by taking away the optical portion and by the application of a lens. However, special stands have been constructed for single microscopes, consisting of a pillar, which either has a separate pedestal, or is screwed firmly to the case in which the microscope is kept. There is a rack and pinion on the pillar, by means of which the stage, which is perforated in the centre, moves up and down; above it there is a ring to receive the lens; under the stage is the reflecting mirror. In other microscopes, on the contrary, the lens is moved by the rack and pinion, and the stage is fixed; a finer screw for the purpose of movement has also been applied, as in the compound microscope, and in general the same apparatus, micrometer, camera lucida, &c., can be used. Different forms of single microscopes have been constructed by Plössl, Pritchard, Ross, Chevalier, Raspail, Lebaillif, and Strauss-Dürckheim.

CHAPTER II.

ON THE CONSTRUCTION OF THE DIOPTRIC COMPOUND MICROSCOPE.

The greater spherical and chromatic aberration of a single lens, or system of lenses—the diminished field of view, as well as the diminished light—the increased exertion for the eye—and the short distance between the object and the lens—constitute defects to which we have already referred in the preceding section, and on account of which the single microscope is scarcely ever used for high magnifying powers, or with lenses that magnify more than twenty or thirty times. Moreover, we make use of another property which convex lenses possess, namely, that of magnifying the *image* of an object. If, for instance, we suppose the object *ab* placed behind a lens; a pencil of divergent rays will issue from *a* and meet the surface of

Fig. 14.



the lens, they will then be refracted, as well at their entrance into the lens as on emerging from it, and at last converge before the lens in the point A. The same is the case with the pencil of rays from the point *b*; the divergent rays will converge on the other side of the lens, and be collected in the point B. From all points between *a* and *b* there will also proceed pencils of rays which are collected between A and B. In this manner an image of the object *ab* will be obtained at AB, but inverted.

In order that an image may be formed, the object must not occupy the focus of the lens, for the rays then become parallel and do not unite on the other side of the lens; nor must it be placed within the focus, for then the emergent rays will become divergent. We have already shown the use of this property in treating of magnifying objects by the single microscope. The object must, however, be situated beyond the focus of the lens, for it is only in this case that the rays become convergent on the other side of the lens (see Fig 7). If the object be placed at double the focal distance, the image becomes precisely as large as the object; if the object be situated at more than twice the focal distance, it becomes less than the object. But this arrangement will not cause the image to be magnified, and we must therefore bring the object between the single and double focal length of the lens, and as near the focus as possible, to form a large image. The image is only seen distinctly when received at a spot where all the points of the pencils of rays are formed; if the rays be allowed to cross—as, for instance, beyond AB—the image becomes indistinct. The magnitude of the image bears the same relation to that of the object, as its distance from the lens does to the distance of the object from the lens. The more convex the lens, the nearer the object must be brought to the lens, but the image will then be formed at a proportional distance, and will appear so much the larger.

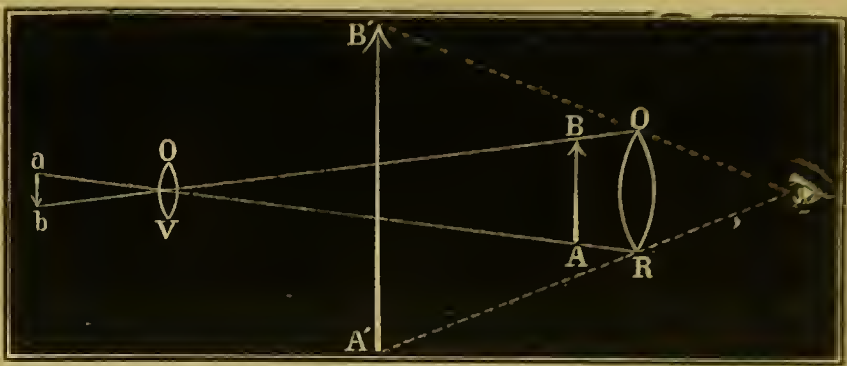
If the rays pass through one convex lens, the image will be inverted; if the rays of this image pass through a second lens, the new image becomes erect, and we may thus obtain inverted or erect images by employing one or more lenses. An inverted object produces, consequently, an erect image when it is formed by one lens.

If we employ another lens to magnify the image, we have a *compound microscope* (*microscopium compositum*). As the image is formed by a lens, it is also called the *dioptric compound microscope*, to distinguish it from the *catoptric compound microscope*, in which the image is formed by means of a concave mirror, and of which we shall speak in the sequel.

The theory of the compound microscope is easy of comprehension, if we bear in mind the two properties we have already mentioned, as belonging to convex lenses,—viz., that of magnifying an object and its image also. The former is effected (see Fig 15) by the lens OV; the divergent rays from the object *ab* are allowed to continue

their course, so that the magnified image exactly occupies the focus of the second lens OR. When seen through this, the image becomes

Fig. 15.



magnified in accordance with the same laws as in the amplification of an object by means of a single microscope. Thus, after the image of *ab* is formed at AB, it is observed through the lens OR, and is seen in the direction RA' and OB' as A'B'.

The lens OV, by which the image is formed, and which is nearest the object, is called the *object-glass;* the lens OR, by which the image is magnified, and which is nearest the eye, is called the *eye-glass*. These two lenses are placed at either end of a *tube;* and between the object-glass and the eye-glass there is a separate lens, called the *field-glass*. The tube is fixed to a *stand*, which, at the same time, supports the stage and the *apparatus for illumination*. We will first consider more closely these principal parts of the microscope.

a. *Of the Principal Parts of the Dioptric Compound Microscope.*

The discovery of the compound microscope is ascribed to Zacharias Joannides, or Jansen, a native of Holland, in the year 1590. His microscope consisted of a copper tube, six feet in length, and one inch in diameter. He presented an instrument of this kind to the Archduke Charles Albert, of Austria, by whom it was given to Cornelius Drebbel, a Dutch alchymist, who was afterwards astronomer at the court of James the First of England, whither he brought the instrument in 1619, and where it was shown to Borelli and several other learned men. Many persons, therefore, ascribed the honour of the discovery to Drebbel. Fontana also claimed the merit

of having made this discovery as early as 1618. The use of compound microscopes soon became much extended; and amongst the first used must be mentioned those of Hooke (1656), Eustachius Divini (1668), Griendel (1687), Philipo Bonnani (1698), and Zahn (1702). Hooke's microscope measured three inches in diameter, and seven inches in length, and might be lengthened by means of four tubes inserted in each other. It consisted of a small object-glass, a field-lens, and a powerful eye-glass. Divini's microscope was also composed of three similar parts; but the eye-piece was composed of two plano-convex lenses, by which the field of view was enlarged, the magnifying power increased, and the spherical aberration diminished; the eye-piece was as large as the palm of the hand, whilst the circumference of the tube was as large as a man's thigh; yet, with this colossal instrument, he could not magnify more than 143 times. Bonnani's microscope, which was still more inconvenient, was horizontal, and moved by a rack and pinion. It was illuminated by a concentration of the light of a lamp, through two glass lenses. Griendel used two plano-convex lenses in all three glasses, so that there were altogether six lenses. Lake constructed, amongst others, a double microscope for both eyes. The great cause of the imperfection of these and other old microscopes was the difficulty of constructing achromatic object-glasses, and even after Chester More Hall (1729), led by the study of the structure of the human eye, perhaps also following Gregory's (1713) ideas on this subject, had discovered achromatism by combining two different kinds of glass, microscope lenses were for a long time not constructed on this principle. Even Dollond, who constructed achromatic telescopes in 1757, did not apply the achromatic principle to the microscope. It was not until 1774, that Euler proposed to employ achromatic object-glasses for the microscope, and his suggestions were first carried into effect four years after by Nicolas Fuss, who constructed a compound object-glass of three lenses, of which the first and third were of crown glass, and the second of flint glass. The attempts of Æpinus (1784) for the same object were unsuccessful, and the lenses of Charles (1800-1810) could scarcely be considered to be achromatic. Brewster's (1812) lenses of glass and of fluids of different density, were not practically applicable. According to Harting, Herman van Deyl is said to have prepared excellent achromatic object-pieces in 1807. Yet Fraunhofer's (1811) achromatic micro-

scopes were the first that were applied to scientific investigations, for before that time the microscope had served chiefly for a toy, or a mere means of amusement. Fraunhofer's object-glass consisted of a single achromatic lens, in which the two glasses were not cemented together; the convex side of the lens was turned towards the object; this lens had not a high magnifying power, and the field of view was small, but the image was more distinct and more strongly illuminated than in object-glasses that were not achromatic. With Fraunhofer a new era in the construction of *object-glasses* commenced. The spherical aberration was not, however, destroyed, because his object-glass only consisted of one lens, which must necessarily have a great convexity, and which was consequently very difficult to grind. Selligues, therefore, made a very important discovery, when he combined several weaker lenses to produce a high magnifying power. In the year 1824, Vincent and Charles Chevalier formed an object-glass in accordance with the arrangement suggested by Selligues the year before, and which consisted of four lenses, which were screwed upon each other, each formed of a plano-concave flint-glass and a double convex crown-glass lens, which were united on their corresponding surfaces. Although the chromatic aberration was undoubtedly much diminished by this arrangement, the spherical aberration was increased when the convex surface of the lenses was turned towards the object, notwithstanding that the aperture of the lenses was very small. Charles Chevalier, therefore, altered the object-glass in such a manner that the plane surface was turned towards the object, and united the glasses of each lens by the help of turpentine or Canada balsam, which prevented dust and damp from penetrating between the lenses, and obviated the loss of light occasioned by the repeated reflection at the surfaces of the lenses, which were turned towards each other. Achromatic object-glasses were subsequently constructed in England, in 1824 and 1825, by Tulley, in accordance with Goring's suggestions, and in Italy, in 1827, by Amici.

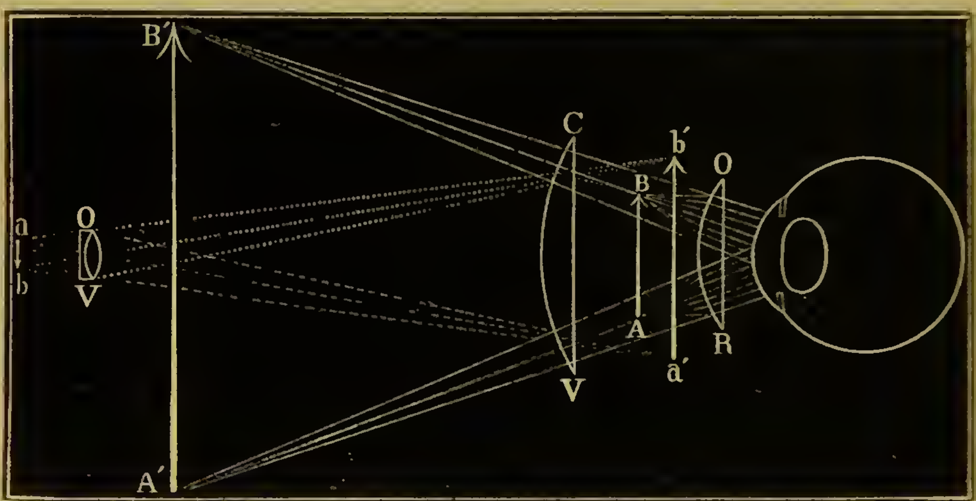
The arrangement first adopted by Selligues of screwing several achromatic lenses upon each other, in combination with Chevalier's improvements, is still in use for object-glasses. The advantage gained by this method is, that the aberration of one lens is modified by that of another, and that they thus become aplanatic; the optician, therefore, who arranges the lenses, must always have a large number from which to make his selection, in order to combine those lenses

together which give the clearest image. As the separate lenses do not possess equal focal lengths; when we are about to examine an object, care must be taken in combining the lenses to preserve the order in which they have been put together by the instrument-maker. Thus the lenses of Schiek and Plössl follow in the order in which they are marked with numbers 1, 1 + 2, 1 + 2 + 3, 2 + 3 + 4, 3 + 4 + 5, 4 + 5 + 6, 5 + 6 + 7, which last is the highest magnifying power. We cannot arbitrarily combine 2 + 4 + 5, &c. Chevalier, Oberhäuser, and others supply their microscopes with fixed sets of object-glasses, having different magnifying powers, consisting of from 1 to 3 lenses; thus the inconvenience of screwing the lenses upon each other is avoided; they become less easily soiled, because it is unnecessary to unscrew them; at the same time, the manner in which the whole object-glass is fixed to the tube, by means of two hooks, avoids the loss of time and the trouble required for screwing on the single lenses. Such fixed systems of lenses deserve, therefore, the preference. (Pl. I., fig. 4.)

Besides the correction of the aberrations, our object-glasses in the present day are distinguished from the older ones by the improvement in the mode of illumination, the greater clearness of the image, and the high magnifying powers which are now obtained independently of the more powerful eye-piece formerly required, and which always gives a more incorrect image; and, lastly, by the greater distance of the object-glass from the object. The higher the magnifying power, the nearer the object-glass is to the object; the proximity on the whole must not be under one-thirtieth of an inch; if it be less, it is very difficult to cover the object with a thin glass plate; the object-glass becomes easily soiled or bedewed when evaporation arises from the object, and is injured by constant wiping. The excellence of the object-glass depends upon the distance that may intervene between it and the object when in focus, without any decrease in the magnifying power. In order to increase the distance between the object-glass and the object, and to enlarge the field of view, Charles Chevalier has constructed an object-glass, consisting of two lenses, between which the distance may be varied; but the object is less enlarged here than with the ordinary object-glasses. Amici makes two kinds of object-glasses, for observing an object either with or without the covering of a glass plate. Brünner is said to make object-glasses having unequal distances between the lenses.

The image formed by the object-glass is observed through the *eye-piece*, and is therefore seen inverted. Formerly only a single lens of high power was used for the eye-piece, in order to compensate for the lower power of the object-glass; but, in consequence of this arrangement, the field of view required to be considerably diminished, and the aberration was not destroyed. At the present day, therefore, a lens is introduced into every good eye-piece between the object-glass and the spot where the image is formed. This lens is called the *field-glass;* it is plano-convex, like the proper eye-lens, and its convex side is also turned towards the object-glass; it is two or three times as broad, and the radius of the curve is in general three times as large as that of the eye-lens; however, it is sometimes made of a more or less high power. The accompanying figure explains the action of the field-glass. By the assistance of

Fig. 16.



the achromatic object-glass OV, the inverted image *a′b′* is formed of the object *ab*. But since the field-glass CV is inserted between the object-glass OV and the eye-glass OR, the pencil of rays is refracted, and the image is formed at AB, exactly in the focus of the eye-glass OR. From this image proceed divergent rays of light, which meet the eye; and hence the image is seen with the eye-glass OR, and found to be magnified in the direction AA′ and BB′ as A′B′. Although the image is certainly diminished by the field-glass, and AB is less than *a′b′*, it becomes clearer, and a greater portion of it can be brought into view at once, or, in

other words, a larger field of view is obtained. The most important object with the field-glass is, however, to correct both the spherical and chromatic aberrations; the latter indeed could be rectified by an achromatic combination of crown and flint-glass, and the former by introducing a diaphragm; but in that case the field of view would be much diminished. A diaphragm is, however, interposed between the eye-glass and the field-glass, to exclude the marginal rays; but the aperture will not be required to be so small as in the case already mentioned. (Pl. I., fig. 5.)

There must be a fixed distance between the eye-glass and the field-glass, so that the image may come precisely into the focus of the eye-glass. They are therefore united in a tube, which is blackened on the inside, to prevent the reflexion of rays of light from its sides. Commonly they are combined without being able to be moved towards each other, and the distance must be so arranged, that the aberrations may at the same time be corrected by the corresponding object-glass. It would be best therefore only to use one eye-piece with the same object-glass; and when an observer has become familiar with his microscope, he soon perceives whether one combination be better than another, or whether the clearest image can only be obtained by the combination of *one* eye-piece with *one* object-glass. Still the same eye-piece is mostly used with several object-glasses; and this may be done when there is no great difference in the aberration of the object-glasses. Amici on this account has also formed eye-pieces in such a manner that the eye-glass can be moved towards and from the field-glass; and this is particularly convenient, when the tube of the microscope is made either shorter or longer to obtain a higher or a lower magnifying power, an arrangement which we shall presently consider.

There are two kinds of eye-pieces; that of Campani, which is the one described above, where the image is formed between the eye-lens and the field-glass; and Ramsden's, where the image is formed before the field-glass; but, so far as I know, the last-mentioned kind, which is applied to some astronomical telescopes, has not yet been used in microscopes.

Eye-pieces are of various magnifying powers; the most powerful are fixed in the shortest tubes. In Plössl's and Schiek's microscopes there are four or five eye-pieces, and amongst these an aplanatic lens, which shows the object clearer and more distinct, and is particularly

useful in the examination of opaque bodies; but it has a smaller field of view, and magnifies less powerfully. In Chevalier's microscopes there are usually fewer eye-pieces—two, a weaker and a stronger one, are, as a general rule, sufficient. The tube in which the lenses are fastened must be cylindrical, and capable of being easily introduced into the tube of the microscope, to obviate the time lost in screwing it on. In conical eye-pieces, as prepared by Oberhäuser, the centricity of the lenses may easily be lost, because they do not rest firmly in the tube of the microscope; in order to obtain a good image the centricity of all the lenses is absolutely necessary,—that is to say, the axes of all the lenses in the whole microscope must be situated in the same straight line.

Fine threads of spider's web, or of the silk cocoon, are often placed across the aperture of the diaphragm, where they serve partly for measurement and partly to show an object to the less practised observer, who may be able to find it more easily when it is seen close to one of the threads.

A pasteboard disc may be fastened upon the eye-piece, especially when working with the horizontal microscope, for the sake of excluding all other light besides that which falls upon the object; the image appears brighter when more rays of light enter the eye through the dilated pupil, and the other eye is less wearied by being held open, or by looking against the light. Charles Chevalier has also fastened upon the eye-piece a little tube with a prism, the base of which is turned towards the sides of the tube. The object of this is to restore the image, which is otherwise inverted, to its proper position; when, for example, the object is moved from right to left, the image goes in the opposite direction, which may confuse the beginner. This apparatus will indeed be superfluous when the observer has once accustomed himself to see the image take a contrary direction to the motion of the object.

The object-glass and the eye-piece are inserted into the *tube* of the microscope in the manner before described. The tube is a hollow cylinder of metal, which, as well as the eye-piece, and for the same reason, is blackened on the inside, and is likewise provided with a diaphragm to exclude the marginal rays. The length of the tube is important; for we have already seen that the image is formed at a greater distance, but at the same time becomes more magnified, the nearer the object can be brought to the

lens; if, therefore, the tube be made longer, the image will be formed at a more distant spot, whilst the rays continue to diverge; or, in other words, the image becomes larger, whilst at the same time the object is brought nearer to the object-piece. But what in this case is gained in magnifying power, is easily lost in distinctness; besides which, we are only able to see a smaller portion of the image. If, on the other hand, the tube is made shorter, a stronger eye-piece must be used, to magnify the object as much as in the former case. Fixed limits, therefore, must be established for the length of the tube, in order that it may not be necessary to use a very powerful eye-piece with a tube that is too short; because, by doing so, the image, on account of the greater intensity of the aberration, always becomes deteriorated; while, on the other hand, care must be taken that the use of too long a tube does not render the image indistinct, the illumination defective, and the field of view too small. To this, also, we may add, that a very long tube makes the microscope inconvenient, especially when it is used in a perpendicular position. When the tube is very long, it is well to have it divided in two or more pieces, which can slide into each other, and be moved with a rack and pinion, that the centricity of the lenses may not be disturbed. For the rest the tube can be lengthened, either by moving the part in which the eye-piece is placed, or the part containing the object-glass; Charles Chevalier has, at my suggestion, adopted the latter arrangement in his larger microscopes.

A method of increasing the power, without lengthening the tube, was first employed by Selligues. He placed a concave lens between the eye-piece and the object-glass, by means of which the rays of the image were made more divergent before it was seen through the eye-piece. It was replaced at a later date in Fraunhofer's microscopes by an achromatic concave lens. The chief advantage of this mode of adjustment is, that the object can be placed at a greater distance from the object-glass; but, as the image loses in distinctness by the increase of the spherical aberration, this method has almost fallen into disuse.

The present is a fitting place to notice the pancratic microscope, in which the magnifying of the object is produced by lengthening the tube. This instrument was first constructed by Chevalier (1841), in accordance with the directions of Fischer, of Moscow. The image formed by the object-glass is seen by means of a compound micro-

scope (that is, a tube with an object-glass and an eye-piece), which can slide up and down in the tube in which the object-glass is fixed; by lengthening the tube the power is increased. In this microscope the image appears in the same position as the object, and not inverted. Instead of the inner object-piece, Merz (1843), Fraunhofer's successor at Munich, has introduced an achromatic concave lens, by means of which the whole microscope becomes shorter, but the image is inverted; he has likewise made the eye-piece moveable by itself.

The tube of the microscope, with its object-glass and eye-piece, forms the optical part of the instrument, properly so-called. In order to regulate all the movements with precision, the tube is fixed upon a *stand*, which supports the stage and the apparatus for illumination, which we shall notice separately. The stand must possess solidity and weight, that it may stand firm; and it must not be too complex in its construction. It consists of a pedestal and a pillar, which supports the above-mentioned apparatus. In many microscopes the case in which the instrument is kept is used for a pedestal, by screwing the pillar firmly upon its upper surface, which must not in that case form the lid of the box, since it will be necessary to open the latter, in order to remove any of the objects that may be required in the course of the observation. When the pillar is fixed in this manner, the whole microscope certainly stands tolerably firm and secure; but as it rests upon a large surface, it will frequently be inconvenient to place the case in a perfectly horizontal position, such as we shall find necessary in conducting our observation. In other microscopes the pillar rests upon a flat or high and heavy cylinder (Oberhäuser); but here also the same inconvenience regarding the horizontal position may be met with. The best arrangement is to have the pillar resting upon a tripod, which can be shut together when the microscope is put away; for although it may perhaps stand less securely, it can more easily be placed in a horizontal position, particularly when proper adjusting screws are attached to each foot of the tripod.

The pedestal bears either a round or an angular pillar. Its height and other adjustments partly depend upon the position in which the microscope is used. If the microscope be used in a perpendicular position, so that the object is seen from above, the pillar must not be too high, because the microscope then becomes inconvenient to

handle when placed upon a common table. If, on the contrary, the object be viewed in a horizontal direction, the height is of little consequence; still we shall have occasion to see that it is most convenient for the delineation of the object, that the distance from the eye-piece to the table on which the microscope stands should be exactly the same as the distance of distinct vision. The pillar, in general, can be divided in the middle by means of a joint, and the perpendicular position of the tube of the microscope can then be made to assume a horizontal or an oblique direction. The stage on which the object is placed either moves with the tube, and the observation is made by looking directly against the light, or the stage remains fixed; in the latter case the tube of the microscope must be divided, and a prism placed in the joint, to change the direction of the rays of light; this is best done by placing the prism as near the object-glass as possible, in order that reflexion may take place before the rays reach the eye-piece.

The tube of the microscope is connected with the stand in such manner that it can either be moved upon the latter or remain fixed. The tube can be moved by sliding up and down in another tube, taking advantage of the resistance caused by friction; but this method is objectionable, because this resistance may become too strong when the tube grows rusty, or too feeble when it wears out. It is better, therefore, that the tube should be moved by a rack and pinion, for which purpose a set of teeth is placed upon the hindmost surface of the pillar, in which a pinion fits with precision; sometimes the pillar supports a lesser one, on which the adjustment takes place, or the coarser adjustment is brought about by the rack, and the finer by means of a separate screw. Still the finer screw is very nearly superfluous, when some practice has been acquired in the use of the rack; but it must be well made, and so fitted that the movement shall not become too firm or too loose, and shall take place in a perfectly perpendicular direction, without working towards either side. If, on the other hand, the tube of the microscope be fixed, the stage must be moveable up and down the pillar, by the same means as the tube is moved in the other case. The stand and the rack are made of brass or steel; the latter becomes easily rusty, which makes the adjustment more difficult, and for this reason a brass rack is perhaps preferable, notwithstanding that the teeth in the course of time wear out more quickly.

Among the peculiar adjustments of microscopes of various forms, we will here mention a rotatory movement of the tube (Amici and Oberhäuser),—the removal of the whole stand from the stage,—so that it becomes free for preparing upon (Oberhäuser); and the rotation of the tube in a horizontal direction (Charles Chevalier), so that the object can be shown to a second observer, sitting on the opposite side of the table on which the microscope is placed. With Chevalier's microscopes, the tube may be so turned that the object-glass lies in a horizontal position, which is convenient in shifting it. In his smaller instrument also, the whole tube and stage may be so turned that the latter turns upwards, and the object-glass stands under it; thus the object is viewed from below. This adjustment may be employed when using chemical agents under the microscope, which are liable to soil or injure the object-glass; or when wishing to warm the stage, in which case vapours from the object would form upon the object-glass and obscure it; the glass plate then used for the object must not be too thick for the higher powers. We will not, however, dwell any longer upon the description of the stand, as it is much more easy in general to get an idea of the construction of various microscopes by seeing them even once, than by studying a detailed and wearisome description of them. Such a description is also of little practical value; for the mechanical arrangement of the instrument is of less importance than the goodness of the lenses, and the practical facility of the observer in using his instrument.

The *stage* serves to support and to retain the object to be examined. It consists of a brass plate, perforated in the middle, having an aperture answering to the centre of the object-glass, which must not be too small, as it will have to serve for the passage of the light from below. It should possess a certain solidity, and be of a proper size (from two to three inches broad and four inches long), to allow preparations to be made upon it. The surface should be quite plain, blackened, and unpolished, that light may not be reflected upon the object-glass. It is best to cover it with a black rough ground-glass plate, to prevent the influence of damp, acids, &c., upon the metallic surface. It is well to have some clamps upon the stage, to fasten the plate upon which the object lies; a spiral spring applied under the stage is often used for this purpose; but it is more convenient when the clamps admit of being detached. There is also frequently an

aperture in the stage for the introduction of a reflecting mirror for illuminating from above.

The construction of the stage varies as much as that of the stand. The practised observer will be satisfied with a simple plate; but for one who is less familiar with his instrument, it is convenient that the movements, which are necessary whilst viewing the object, when it requires to be shifted backwards and forwards under the object-piece, should be regulated with the greatest precision. The stage, therefore, has been so constructed as to be capable of being turned upon its axis (Oberhäuser), to admit of the object being illuminated from all sides; or it has been composed of two plates lying upon each other, the movement of which is performed by two screws, the one to carry the plate backwards and forwards, the other from side to side. If both screws work together, the plate, and consequently the object upon it, move in a diagonal direction. As both hands must be used in this mode of adjustment, Turrell has ingeniously placed the two screws upon one side of the stage, so that the axis of the one screw is perforated to receive the other, by which means the stage may be moved with one hand both backwards and forwards, and from side to side; and when both screws are handled at once, also diagonally. This stage deserves to be recommended. (Pl. I., fig. 6.)

The stage is attached to the stand either as a fixture, or is moved by a rack or screw, similar to the one employed in the tube of the microscope. Some persons prefer the stage to be immoveable, because it is then more solid to make preparations upon, and is not liable to be displaced on taking measurements. The first reason is of little importance, as rough preparations of large bodies are never made under the microscope; while the latter objection would argue in favour of the immoveable stage when the screw micrometer is employed. Nor is it necessary to change the illumination, in order to insure that a proper section of the cone of rays issuing from the reflecting mirror shall always fall upon the object. On the other hand, the eye cannot be kept so steady when the optical portion of the microscope is moveable, but must constantly follow the motion of the eye-piece; if, moreover, the rack and screw are not well made, the tube easily inclines towards the sides, or loses its perfectly perpendicular position, by which the observation is disturbed. If the stage be solid, and fastened securely and steadily to the stand, and if all the racks and screws be made with precision, and

can be moved without shaking, it seems quite immaterial whether the stage or the tube of the microscope be moveable. Supposing the instrument to be thus carefully constructed, it is convenient to have both portions moveable with a rack or finer screw. The observer soon accustoms himself to use one or other adjustment exclusively.

If we recapitulate all the movements applied to the tube of the microscope and the object-table, they are as follows :—The adjustment of the stage with the rack or finer screw, the same movement of the whole tube, the movement of the object-glass alone, or with the eye-piece alone, together with the lengthening of the tube.

We come now to the last of the principal parts of the microscope, —namely, the *illuminating apparatus.* Even when using weaker magnifying powers, such an apparatus is indispensable, on account of the faint light of the microscopical image ; and this is still more important when higher magnifying powers are employed. It is only when very low powers are used, or when the object-glass is directed exactly against the daylight, that it will be possible to dispense with a separate illuminating apparatus. But this method can only be applied in the case of solid bodies, which must be fixed with a clamp upon the perpendicular stage ; objects, on the contrary, in a fluid would sink down, and vanish from the field of view. In general the object-glass is never turned towards the light, except with small hand microscopes with a low magnifying power, or when the object is glued upon the object-glass, as in the above-named lenses.

A different mode of illumination is required for opaque and transparent bodies. With opaque bodies the rays of light are allowed to fall upon the object in the same manner as usual, only their number and intensity are increased; transparent bodies, on the contrary, are illuminated by causing the rays of light to be reflected by a mirror under the stage, so that they *pass through* the object. Hence the difference between illumination with reflected and with transmitted light.

If the body be opaque, common light, as we have already stated, can be used only with low powers. Its intensity will be increased for higher powers by collecting the rays of light with a large lens or prism (Selligues), and then allowing them to fall upon the object. The lens, which is either bi-convex or plano-convex, must be large. in order that it may collect many rays of light ; the prism is tri-lateral, with plane or curved surfaces. They are either fastened upon a rod

in an aperture in the stage, or, what is better, upon a separate stand with a heavy foot, upon which they can be moved up and down, and in any direction that may be desired. In this manner we obtain refracted rays of light; but the object, which should rest upon an opaque plate, can only be illuminated from one side, and from that one, namely, whence the light comes, while it is impossible to apply any high magnifying power. It is better to illuminate opaque bodies by means of a Lieberkühn mirror. This consists of a mirror of glass or metal, more or less concave, in the centre of which the object-lenses are placed. Under the stage, which, in this case, must have a large aperture, there is placed a concave mirror (the reflecting mirror, to which we shall more specially direct our attention in the sequel), from which the rays of light are thrown upon the Lieberkühn mirror, and from thence again upon the object, which must rest upon a glass plate, that the course of the rays from the reflecting mirror may not be interrupted. Thus the object becomes equally illuminated from all sides, while, at the same time, a high magnifying power can be used, when the mirror is not too large or too much curved. For this purpose it is preferable to apply the object-lenses towards the centre of the curve, and not where they are usually received just within the periphery of the mirror. (Pl. I., fig. 7.)

For the illumination of *transparent* bodies, a reflecting mirror is used, which is placed under the stage. It is best to have it fastened upon the stand, so that it be moved up and down upon it; sometimes it may be made to move with the stage, and it should also move freely in all directions. It should therefore be inserted in a ring, in the same manner as a Cardan's lamp; although it varies in size, it is better for it to be too large than too small (three to four inches in diameter). It is usually of a circular form. Goring uses elliptical mirrors, and thus obtains cylindrical pencils of rays. These reflecting mirrors are commonly double, having a concave mirror on the one side and a plane mirror on the other. The latter is used when the light is very strong, and is sufficient for lower magnitudes. A black plate is substituted, in some cases, for the plane mirror, to afford a dark ground for observing opaque bodies. The mirror is turned towards the light, and the rays of light are reflected from it upon the object. In many cases, however, this light becomes too strong, so that very transparent bodies would be invisible. Various means have therefore been devised to diminish the quantity

of light. Thus the reflecting mirror may be covered with more or less broad dark rings of thin pasteboard or paper, so that the surface of the mirror, and the quantity of the rays of light, may be simultaneously diminished. But this method is very inconvenient, and is no longer used. In the place of this a moveable diaphragm, with four or five circular apertures, is now applied under the stage; the size of the apertures must partly depend upon their distance from the stage. The distance of the diaphragm from the stage is, however, an essential condition in this mode of adjustment; for if the former be removed to a greater distance from the latter, a more equally spread, but at the same time a fainter mass of light will fall upon the object, when the rays pass through a larger aperture; while if, on the contrary, the aperture be smaller, but nearer the stage, a mass of light of smaller extent, but of greater intensity, will fall upon the object. The latter mode of arrangement is to be preferred in high magnifying powers, when we wish to concentrate the whole mass of light upon a single point. Where a mass of light is dispersed over a wider surface, a larger portion of an object can be taken into view with a lower magnifying power. As it is easier to diminish light than to increase it, the diaphragm should be placed as close under the stage as possible. (Pl. I., fig. 8.) Oberhäuser prepares loose diaphragms, consisting of a little cylinder or plate, with a very fine aperture, through which a fine but very intense pencil of rays may pass. This diaphragm is so applied, that the opening comes directly under the glass plate upon which the object rests, so that it corrèsponds precisely to the centre of the object-glass. But the mechanism by which the loose diaphragm is inserted, is inconvenient, because each time it requires to be shifted it is necessary to remove the object, and thus the observation is disturbed. It is, therefore, best to introduce a moveable disc, with apertures of various sizes, but, as before said, as close as possible under the stage. A coloured glass is occasionally inserted in one of the apertures.

In order to increase the light from the reflecting mirror, lenses are used, which are placed under the stage, and concentrate the light upon the object. Brewster (1820) used for this purpose four lenses, each of which refracted a pencil of light upon the object through its aperture. Thus it was illuminated from four sides, and the apertures could be closed at pleasure. Wollaston (1829) applied a plano-concave lens under the stage, with the plane side turned to-

wards the object; it concentrated the light received from a plane mirror, and refracted it upon the object. Brewster modified this apparatus (1831), so as to allow the light, concentrated by a double convex and periscopic lens, to fall upon a plane mirror, whence it was again reflected upon a system of lenses composed of two similar lenses, and finally refracted from the latter upon the object. In addition to an illuminating apparatus, made by Goring, we must mention one constructed by Dujardin (1838). It consists of three achromatic lenses, which are united in a tube that is placed under the stage. The light passes in parallel rays from a prism or a plane mirror, and is gradually concentrated by lenses, the strongest of which is immediately under the object, which is placed in its focus. If the light be too strong, a shade, having apertures of various size, is set before the prism. (Pl. I., fig. 9.) Oberhäuser has added diaphragms with very fine apertures to Dujardin's apparatus. Merz has also (1843) constructed an illuminating apparatus, consisting of a tube with two lenses, which is moveable towards a prism, whence they receive the rays of light.

All these forms of apparatus are constructed upon the principle that it is necessary, in order that the object may be sufficiently illuminated, that it should be in the focus of the rays of the light proceeding from the mirror or from the lenses. But, although this is correct in theory, it is found that it is altogether unnecessary in practice, and that, with the present construction of our microscopes, sufficient light is obtained without this apparatus, and without the object being precisely in the focus of the rays of light; and this kind of apparatus may then, in my opinion, be entirely dispensed with. We must, moreover, consider the inconvenience arising from the fact that this apparatus requires an object-glass of a certain thickness, when the lenses are placed immoveably under the stage, and that it is somewhat complicated, and requires practice in its use. The simplest manner of applying a concentrating lens is that which Amici adopts in his microscopes,—namely, a plano-convex lens, which can be moved up and down a pillar, receives light from the mirror, and throws it upon the object; this mode of adjustment requires the use of a diaphragm. The light may also be rendered more intense by Selligues' lens and prism, already referred to, whose rays are suffered to fall upon the reflecting mirror. Robert has applied a lens, having a focal distance of one-third of an inch, under

the stage, in the focus of a concave reflecting mirror, in order to illuminate the object with parallel rays, which he considers better than convergent. Reade allows rays of light to fall obliquely upon the object, so that the light is not transmitted; hence it follows that the object is seen upon a dark ground, the remaining portion of the field of view not being illuminated; but this method can only be used with a low magnifying power, where there is a great distance between the object and the object-glass. It is not necessary, however, to make use of any of these forms of illuminating apparatus.

b.—*Of the Secondary Parts of the Microscope.*

As microscopical examination of organised structures is founded upon a preceding anatomical examination, it is natural that a portion of the apparatus, which is indispensable for anatomical investigations, should also be applicable to microscopical observations. The modes of investigation vary, however, and hence the customary dissecting apparatus must also be somewhat modified. To this must be added, that there are various appliances which are a necessary result of the general mode of construction of the microscope; and, lastly, some which are used in special investigations, or modes of investigation. We shall speak of the apparatus for measuring and delineating objects when we treat of the use of the microscope.

Amongst the ordinary appliances of the dissecting microscope, we will only mention the following:—coarser and finer forceps; self-acting forceps, which hold the object fast under the object-glass, after being fixed upon the stage; knives of various form and size, such as Valentin's *double-bladed knife*, to cut fine slices of equal thickness: this knife consists of two flat blades, sharp on both sides, and which, by means of a screw or a slide, can be fixed parallel to one another, and at different distances apart, according to the thinness of the slice required (Plate I., fig. 10); Oschatz's *microtome* is also useful for cutting fine slices; it essentially consists of a horizontally-placed knife, which, by means of a peculiar complicated mechanism, is put into a rapidly sawing motion; the object is secured in front of it in a case, which can be placed at various elevations before the knife, by means of a micrometer-screw; the thickness of the slices can be fixed previously, and they may be obtained of extreme and uniform thinness; the instrument is also so constructed that

the slice may be cut off under water; pointed and curved *needles*, which should be attached to a flat handle, that they may not roll away on being laid aside; cataract needles, *quills* cut to a point; *scissors* with a broad blade; Strauss-Dûrckheim's microtome, consisting of scissors which terminate in two sharp plates; fine glass *syphons* or funnels, used partly to take up minute bodies—for instance, infusoria—out of a glass, partly to add a drop of fluid to a preparation; *wax and cork plates*, for fastening bodies during the preparation; cork plates may be furnished with an under surface of zinc or lead, to prevent warping by moisture, and to enable them to sink to the bottom, when a preparation is being made under water; various *glass vessels*, *grindstones*, *saws*, *files*, and *chisels*, for the preparation of hard bodies (for example, teeth), *camel-hair pencils*, *a blowpipe*, *a syringe*, *injecting apparatus*, &c. It is well to accustom one's self to use as few instruments as possible.

Glass plates are indispensable, whatever be the construction of the microscope. Objects are spread upon them for the purpose of being examined with transmitted light. Their size and shape should be regulated according to the size and form of the stage. The glass of which they are cut must be plate-glass, colourless, without any tinge of red, green, or blue, without streaks or air-bubbles, and free from any admixture of the red oxide of iron which being used in polishing the glass, is not unfrequently met with when examining the plate under the microscope, and gives rise to errors; hence care must be taken to examine the glasses before they are used. They may be about the twelfth part of an inch in thickness; if very thin, they easily break when they are cleaned or thrown down. Concave glasses—as, for instance, small watch glasses—may be used in examining an object which swims in a larger quantity of fluid. Living animals may also be enclosed in small cylindrical glasses; but small boxes, impervious to water, and made of plane glass plates, are better suited to the purpose. Glass rings are also useful for the same object; these rings must be cut from a glass tube, and be fastened with putty upon a glass plate, or a concave and a plane glass, or two watch-glasses may be united together in a metal ring,—as, for instance, to hold a living animal, &c. Every one constructs these appliances best in accordance with his own plan. Coloured and black glasses have also been used for opaque bodies, but here the nature of the ground is of little consequence;

small plates of wood, painted black, are most convenient for the purpose. Thin glass plates are used for covering the objects which are examined; square ones are the best, of about half an inch in diameter, for they are easier to take hold of, and to lay upon an object, than round ones. They must not be too thin, because they break easily when they are wiped; on the other hand, they must not either be so thick as to press the object with too much force, or impede the object-glass from approaching it, and thus prevent it from coming into focus. For the rest, what has already been said of the larger glass plates is alike applicable to these. Laminæ of mica are not so good, on account of their scratches and their fragility; still they may occasionally be used.

Amongst the different kinds of apparatus, we will first mention the *compressorium*, which, as we shall find, is necessary for the examination of many objects that may require previous pressure. By the employment of this instrument the particles are spread out at a greater distance from each other, over a more extensive surface, are fixed, and are brought to lie in one and the same plane. This object is already partly attained by the super-position of a thin glass plate, which works by means of its own weight. In order to increase the pressure, especially on elastic objects or harder objects, which are to be crushed, and in order to make it more uniform, a special apparatus has been constructed, which was first brought into use by Purkinje in 1834. His compressorium consists of a circular plate of brass, having a common glass plate in its centre. A brass frame, with a thinner glass, is screwed perpendicularly upon the object, by which it can be pressed with greater or less force. The frame is turned outwards, beyond the margin of the brass plate, before the object is introduced, and is shut by a hook, which takes hold of a peg. Although Purkinje and others use this instrument in all their investigations, it seems too complicated and heavy. The glass used in pressing must be pretty thick, which necessarily prevents the use of an object-glass having a short focal distance; if it be too thin, it easily breaks, and cannot be restored so readily as that in Schiek's compressorium. (Pl. I., fig. 11.) This consists of a square brass plate, with a glass plate in the centre; upon this rests a thin glass plate in a brass ring, which is balanced in the bifurcated end of a balancing rod, fastened in the middle of the subjacent brass plate. By turning a screw, the other end of the rod is raised, and the brass ring pressed downwards;

but as it only balances at two points, the pressure is not so uniform, as with Purkinje's compressorium, in which it is completely perpendicular. The object, therefore, is very liable to escape when it is elastic. Oberhäuser, Pacini, Amici, and Wallach have made some alterations of less importance in Schieck's compressorium. In order, at the same time, to cause the object to roll or to fold itself, when it is a membrane, Mandl added a screw on one side of Schieck's compressorium; by moving the screw the upper plate is drawn over the object, and produces this effect. Quatrefages has applied four small pins to the upper surface of the compressorium, to set it in a horizontal position, when turning it round to view the object from the opposite side. Dujardin also has somewhat altered it, in order to be able to use it in connection with his illuminating apparatus.

The compressorium must be made with such nicety as to keep both glass plates always parallel to one another; because, unless they be so, the pressure will not be uniform. If the glasses become scratched by use, they must be changed. When the compressorium is used, care must be taken not to apply too much force, lest the thinner glass should give way, and the preparation be destroyed; this particularly occurs with very hard substances, or when, for instance, a grain of sand is accidentally mixed with a soft object. The use of the compressorium is in fact much less common now than when Purkinje first introduced it; and, on the whole, it can be very well dispensed with. It can be applied for the crushing of harder bodies, as well as for the demonstration of an object which we desire to hold firm without its moving; but even here its place may be supplied by placing small balls of wax between the glasses, for the purpose of moderating the pressure. With a little practice, we soon learn to estimate the amount of pressure that an object may bear or require, and this may easily be applied by pressing upon the upper plate with a needle or the point of a knife.

Certain bodies, as for instance tourmaline and Iceland spar, possess a power of double refraction. This property of Iceland spar was discovered by Bartholin in 1669. After the discovery by Malus in 1810, of the *polarisation of light* by such bodies, Talbot was the first who made use of polarised light for the microscope; it was subsequently applied by Brewster. If a single lens be used, it is covered with a plate of transparent tourmaline, or the lens is com-

posed of two plano-convex glasses, between which the tourmaline plate is glued by means of Canada balsam. A second tourmaline plate is also placed under the stage, or it may be inserted in one of the apertures of the diaphragm. The tourmaline plates are so placed towards each other, that the light from the reflecting mirror is polarised—*i.e.*, cannot be transmitted on account of the peculiar refraction, but the field of view appears black. If now an object be laid upon the stage, it depolarises the light, and appears in strong colours upon the opaque ground. In the same manner polarisation is applied, in the compound microscope, by placing one tourmaline plate under the stage, and another upon the eye-piece; but as tourmaline plates are always a little coloured and opaque, Nicol first used in their place two prisms of Iceland spar, and inserted them in the manner above named. By these means, however, the field of view was considerably diminished; and Charles Chevalier, therefore, introduced the one prism into the tube of the microscope, between the eye-piece and the object-glass, immediately above the latter; whilst the other prism was placed in the usual position under the stage, but was moveable, and could be turned round until the field of view became dark. The object which is then placed upon the stage depolarises the light, as before mentioned. For the purpose of polarisation, glass plates may also be used, which require to be fixed in a peculiar manner.

I must observe that, although I have worked much with Nicol's prisms, I have not found the polarising apparatus in any form worthy of the extended application it has received at the hands of several observers. It is only applicable to the observation of certain objects, as, for instance, crystals, the structure of the globules of starch, or of the lens of the eye. In general, however, structural characteristics can scarcely be said to be shown with increased distinctness under a microscope illuminated with polarised light.

The polarisation above referred to is the ordinary form. Circular polarisation, which is used for ascertaining the density of various fluids (such as different kinds of beer, solutions of sugar, as, for instance, diabetic urine) has not yet been employed with the microscope.

Such a separate *electrical apparatus* as Plössl has constructed, to observe electrical phenomena under the microscope, will still more rarely be required. A rotatory electrical apparatus has likewise been

applied, in recent times, to excite the contractions of the fibres of muscle under the microscope (Weber). In order to protect the object-glass against chemical agents, or on sinking it in a fluid, a *protector* is used, consisting either of a little glass bell, or of a small cylinder, with a plane glass at its extremity, which is screwed upon the object-glass; if we wish to make an observation in a horizontal direction, a prism in a tube may be applied to the object-glass, and then be allowed to sink down into the fluid. Wagner and Donné have constructed special forms of apparatus, for showing the circulation of the blood in the web of the feet of frogs. For this purpose I make use of a cork plate, upon which the frog is bound fast, after being enveloped in a piece of linen; the leg and each of the toes are put into loops of thread, which are drawn through the cork plate, and are so fastened that the web of the foot is extended, and comes immediately over an aperture in the cork plate of several lines in diameter, through which the light falls; by tightening and loosening the loops round the leg, the circulation can be alternately accelerated or retarded. These, and a similar apparatus for special investigations, may readily be adapted to the peculiar tastes or requirements of the observer.

Finally, microscopical investigations very often require the employment of *chemical substances*. Among these we may especially reckon distilled water, alcohol, turpentine, Canada balsam, various acids, especially acetic, chromic, sulphuric, muriatic, and iodic, (which Platner recommends for the demonstration of the nuclei of cells instead of acetic acid), solutions of carbonate of potash, and of caustic potash, common salt and sugar, tincture of iodine for the detection of starch, etc. Charles Chevalier has constructed a pyro-chemical apparatus, consisting of a stage, under which two spirit lamps are placed, for the purpose of warming it and the object upon it.

We may conclude this section with a brief notice of the case in which the microscope is kept; and which should be constructed in the same manner as other cases intended for the preservation of instruments. It should be solid, but not clumsy, and composed of dry materials, which will resist dampness. A commodious arrangement of the objects in the case, by which they may be secured from concussion or from being shaken when the instrument is moved, is an essential requirement. In this respect French instruments are

superior to others. It is best to have the case covered in those parts, where it may be necessary, with velvet or cloth, but not with leather. It will be found convenient, when travelling, to have a more simple outer case, in which to secure the instrument from all risk of injury.

CHAPTER III.

DIRECTIONS FOR THE USE OF THE DIOPTRIC COMPOUND MICROSCOPE.

The practical management of the microscope is much more easily acquired through the instruction of some person skilled in using it, as well as through private study and personal application, than by attention to a number of rules, which, from the nature of the subject, must necessarily be very imperfect. We must, moreover, take into account the variety in the construction of the instrument, the different properties of the lenses, the individual dexterity and powers of the observer, together with the diversity of the objects for which microscopical observations are made. For whilst some persons only make use of the microscope for the sake of amusement, or merely to observe the variety of the forms of objects, others seek to prove the signification of these forms by discovering the principles and laws by which they are governed. It is only whilst both classes continue to be simple observers, that the method of using the instrument will be the same; for as soon as an attempt is made to explain the observation, a different arrangement of the object must at once be adopted; and as here especially the instruction given can only be of a general character, it is most essential to possess an intimate acquaintance with the instrument, great industry and perseverance, and that keenness of sight which can only be acquired by long-continued practice.

In the following pages, therefore, we can only give instruction in a general manner, purposing in this chapter merely to indicate the rules to be observed for the preservation and arrangement of the microscope, for the illumination and the choice of magnifying powers, and for the selection, preparation, observation, and explanation of the object; finally, we will treat of the measurement, delineation, and preservation of objects.

Every one who possesses or makes use of a microscope must be especially careful of its *preservation;* and, indeed, the condition in which an observer keeps his instrument may be regarded as a test of the manner in which he conducts his observations. When a microscope is in constant use, it is best not to take it to pieces; it may be preserved against dust, etc., by covering it with a pasteboard or thin wooden case, the seams of which should have paper pasted over them. Although a bell glass may be more ornamental, it is more liable to accidents, and does not prevent the injurious effect of the direct rays of the sun.

The instrument must of course be preserved from damp, injuries from blows, or other violent concussions, which might disturb the concentricity of the lenses. It is less easy to preserve the lenses free from dust or finger marks. The dust may first be removed by means of a soft camel's hair pencil; if it be necessary to polish the lenses, particularly after they have become damp or moistened by contact of the fingers, a piece of fine soft linen may also be used, which has not been worn threadbare, lest the flakes of thread should adhere to the lenses, and disturb the observation. Soft leather is not so good, for it becomes stiff after having been wetted, and foreign substances, as for instance grains of sand, easily penetrate it, and scratch the lenses, when they are being polished with it. It is still worse to polish the lenses with silk, which often leaves a thin greasy covering. To polish the lenses, it is best to make a rotatory movement of the hand, so that in case of their becoming scratched from any cause, the scratches may be concentric with the periphery of the lens, which is less injurious than when they cross its centre. Should the lenses become smeared, a little turpentine may be used in polishing them; but it must be done quickly, so that the turpentine may not penetrate between the two glasses of the lens, when they are united with turpentine or Canada balsam. If chemical substances have been used, especially those from which moisture could be accumulated upon the object-piece, the lenses must be polished immediately after the observation. In this respect hydrosulphuric acid will act most injuriously upon the flint-glass, which contains a large proportion of lead, and which, in our achromatic object-glasses, has its inferior plain surface exposed; care therefore should be taken not to leave a microscope in a chemical laboratory. If a microscope is brought in winter from a cold room to a warm one,

and becomes damp, it is better either to wait till the moisture has disappeared, or to hold the microscope a few moments close to the fire, rather than to clean the whole instrument. In general, it is better to avoid frequent polishing; and this is the less necessary in the case of the object-glass, because it is turned downwards, and in general only becomes dirty from carelessness, when the object to be observed is placed under it; the eye-piece, which is turned upwards, becomes more easily dirty or smeared from contact with the eye-lashes.

What has been noticed in reference to the lenses, applies equally to the glass slips on which the objects are placed, and the thin glass plates; these should be polished when necessary with fine linen, moistened with water or turpentine; care must also be taken to have them clean, whenever the object to be viewed is placed upon them. As glass plates are not expensive, the same glasses should not be used during a very long time, because they easily become scratched in polishing. The new glasses should be tested before they are used, in order to ascertain whether they are scratched or otherwise injured, and whether any foreign substance is attached to the glass or the object to be examined, since in that case they will not have the same focus. By turning either the eye-piece or the object-glass upon its axis during the observation, the exact position of the dust or the scratch will be detected during the movement.

Many observers always make use of the microscope in a perpendicular position; others in a horizontal one. The preference is chiefly regulated by habit. If the microscope be used in a perpendicular position, it is necessary to stand whilst taking the observation; hence, if a person be engaged during several hours continuously, he will be liable to suffer from weariness of the system generally, and more particularly from pain in the muscles of the neck, and oppression of the chest; it is also said that the lacrymal fluid may flow down in front of the cornea, and thus, by being collected in greater quantity, disturb the observation; this objection is perhaps more theoretical than real. A person using the microscope horizontally has the advantage of being able to sit whilst making his preparations, as well as during the observation; all the motions of the hand will also be more certain, as the elbow can rest on the table,—this position also is most convenient, when the observer wishes to sketch an object with the camera lucida; but the degree of illumination is per-

haps somewhat weaker than in the perpendicular position, for a prism must be applied when the tube of the microscope is bent.

After ascertaining that the instrument is in a proper condition, care must be taken to adjust all its parts with precision. The table on which the instrument is placed must stand firmly, in order that external disturbances may not produce any tremulous motion; this is very easily felt during the observation,—thus, even when any one walks up and down the room, the motion of the object under the microscope will not escape the notice of an attentive observer. The surface of the table must further be horizontal, or the microscope must be brought into a horizontal position by placing something underneath it, or by means of regulating screws, where such exist; otherwise objects, when swimming in a fluid, will follow the laws of gravity, and often disappear entirely from the field of view. It will, of course, be understood that the table must be of a proper height for the observer, whether he sits or stands, so that his movements may not be interfered with, or that he may not be wearied by his position. It is well to have a separate table on which the microscope and the other apparatus can be kept.

The *illumination* may be effected either by common daylight or artificial light. If daylight be used, the window in the room in which the microscope is placed should rather face the north; for the steadiest light is obtained by this means, and the observer will not suffer impediment from the direct rays of the sun. It would be almost superfluous to close the shutters of the other windows, and only to allow so much light to penetrate as could fall upon the reflecting mirror, so that the pupil of the eye might be more distended and receive more rays of light. It is, moreover, a hindrance to the preparation and delineation of the object to be examined, if the whole room be not duly illuminated. To exclude all the reflected light from the object, a screen may be fastened before the stage and the object-piece. The view must be as free as possible, and not be obstructed by high and more particularly dark buildings, or by objects that move to and fro before the window. A sky with white clouds affords the best light, according to my experience; there are but few who prefer a clear blue sky. If the sky be blue, and there be white clouds occasionally passing over it, the observation is disturbed, because the illumination is changed every moment: in cloudy weather, the light is generally insufficient. The direct rays

of the sun must never, indeed, be used as transmitted light, excepting, perhaps, in the examination of some less transparent objects, and then only for a few moments. The strong light of the sun affects the eyes, and attempts have been made to counteract this objection by attaching coloured glasses (blue or red) to the eye-piece, or over the object-piece; it further causes very transparent objects to become altogether invisible, and produces a disturbed image of stripes and flames in a tremulous motion, which is still more increased when the object is not perfectly at rest; objects also, on account of the diffraction of the rays of light, appear surrounded by iridescent borders. Many old and even modern errors owe their origin to making use of strong solar light. Goring has advised that the direct rays of the sun should be so employed that they may fall upon a reflecting mirror, covered either with plaster of Paris or white paper, and from thence be reflected upon the object; but nothing more is obtained by this method than by means of common daylight. On the contrary, the direct rays of the sun may sometimes be applied for the observation of opaque bodies that are to be magnified in a lesser degree, or of bodies of deep and brilliant colours.

When artificial light is used, it is best to take an Argand lamp, with pure white and steady light; wax or tallow candles are objectionable, because the flame does not burn steadily, and because the candle burns down during the observation, so that the position of the reflecting mirror or that of the candle must be constantly changed. I do not know if camphine light be applicable to microscopical investigations. It is superfluous to use more than one, as the reflecting mirror cannot be directed to more than one light at a time. It is best to place the lamp so that the distances from the mirror to the object and to the light are about equal.

On the whole, I must dissuade my readers from the application of artificial light, though I know that many distinguished microscopical observers always carry on their labours in the evening. Artificial light tries the eye much more than the light of day; it is less steady, and hence one frequently observes a certain tremor in the objects under examination; their colours, besides, become indistinct; and no one surely will deny, that anatomical investigations are always attended with greater difficulties in the evening than in the day.

It is only for the observation of opaque, particularly deeply-coloured objects, — viz., injected preparations, — that I would give it the preference, especially when a high magnifying power is required. Griffith's advice, to suffer the light of a lamp, in which yellow is most frequently the predominant colour, to pass through a glass provided with the complimentary colour of the light, and by this means to produce pure white light, is as incorrect, in a theoretical point of view, as Brewster's idea of applying homogeneous light; it is deficient in practical accuracy. If the object to be examined be opaqne, the reflecting mirror is not used, excepting with the Lieberkühn ; under all other circumstances, the object is to be observed with reflected light, the intensity of which should be increased by the means already mentioned. If Selligues' lens be used, the strongest light is obtained by turning the plane side towards the light and the convex one towards the object,—that is to say, where the lens is plano-convex; with artificial illumination, the light mnst be brought very near the lens.

On the other hand, if transmitted light be used, the reflecting mirror must be placed more or less obliquely towards the point from whence the light proceeds, and it will then be readily discovered, by means of different movements of the mirror, how to obtain the strongest light. When daylight is used, which we always assume to be the case in the following remarks, it is observed that the field of view is at times illuminated with a stronger and a redder light, at other times with one that is weaker, and of a more bluish colour. None of these kinds of light are, in general, good for observations ; but the mirror must be so placed that pure white light may be obtained; to do this, it must often be turned somewhat round to the side ; this is also necessary when an object, placed immediately before it, hinders the admission of the light. In order to obtain good illumination, the reflecting mirror must sometimes be brought nearer or removed further from the object, provided the construction of the microscope admits of this to and fro movement of the mirror.

We have already discussed the means by which the illumination may be increased, and those by which it may be moderated with a diaphragm. If there be no diaphragm to the microscope, which will hardly be the case with new instruments, the position of the mirror must be altered, or it must be shaded with the hand.

Although it may be less convenient to do this than to shift the apertures in the diaphragm, there are still many circumstances under which this mode of proceeding may be advantageously adopted; indeed, some observers constantly move the mirror during the observation, in order to get the object variously illuminated, and chiefly to have it illuminated from one side whilst the shadow falls upon the opposite side; this also may be obtained with the diaphragm, when only the half of one of the apertures is used. Most observers, in the meantime, let the mirror remain unaltered when once properly adjusted; care must then be taken that the screws on which the mirror turns do not become loose and the position be thus altered during the observation. If the illumination be changed, it is sometimes necessary slightly to alter the distance between the object-glass and the object.

As regards *the choice of the proper magnifying power*, I have already several times advised the use of weak eye-pieces and strong object-glasses; because, by that method, a better image is obtained than *vice versa*. Object-glasses are usually made with greater precision than eye-pieces; and although the image, when once formed by the object-glass, may be made to appear larger when seen through the eye-piece, it is not rendered clearer or more distinct. Beginners frequently err in this respect, because it is more convenient to have a great distance between the object seen and the object-glass, with a powerful eye-piece and a weak object-glass, both when the object is to be brought upon the stage as well as during the observation; it may easily happen that the object-glass comes in contact with the plate on which the object rests, and thus the object is put out of its place, and the lens becomes soiled. Where the eye-piece is very powerful, its surface becomes too small to take in the whole image formed by the object-glass; for the magnitude of the field of view and the strength of the illumination decreases, according to the diameter of the object and eye-pieces, or according to the magnifying power employed. It is better, therefore, for beginners to choose an object-glass of lower power, and employ it to search for the object, and bring it to the middle of the field of view; it will then be afterwards found with much more certainty with a more powerful glass. The more practised observer can, of course, at once apply the magnifying power that he considers the best adapted for the observation.

Care must be taken generally to vary the magnifying power as little as possible, and, where it is practicable, the same microscope should always be used by the observer; since it is more easy by this means to become acquainted with the whole construction of the microscope and the properties of the lenses, and to discover what combination of the object-glasses and eye-pieces produces the best image. Moreover, the real magnitude of different objects may be more quickly determined, and at the same time their proportion can be more easily made apparent to others, when only one or two different magnifying powers are made use of in the delineation. One not unfrequently finds upon the same plate objects delineated according to various, although perhaps only slightly different, scales, and thus the mutual comparison of the size of objects is attended with considerable difficulty. On the whole, two degrees of magnitude, one lower and the other higher, will be sufficient. For the lower power, a linear amplification of from 20 to 50 diameters may be employed. As a higher power, a linear amplification of 300 to 400, at most 500, diameters will be sufficient. Such a power is made use of by most good observers; indeed many carry on their researches generally with powers that magnify only 300 times. A high magnifying power is not so important as a correct and distinct image. Very high powers, magnifying 1000 times or upwards, most frequently produce a bad image, partly on account of the weakness of the light, partly because the contours of objects seen do not show themselves with sufficient distinctness; it is but seldom that it will be necessary to have recourse to such high powers for the examination of the more delicate parts of objects.

We have already spoken of the different modes in which object-glasses are combined with eye-pieces, and we shall presently see that every one must calculate the power for himself. In order to increase the power, one can either alter the eye-piece or the object-glass, or both, or lengthen the tube of the microscope; but, as we have before observed, although the image becomes larger when the latter method is adopted, a loss is sustained in point of light in the size of the field of view and in the sharpness of the image. This method should, therefore, seldom be had recourse to.

The preparation of the object to be examined requires the same precision and dexterity as an anatomical dissection; for the success

of the observation depends upon care in the preparation, and it is only in rare cases that this carefulness of manipulation can be dispensed with. But the multiplicity of objects, not less than the individuality of the observer, precludes the establishment of more than general rules for the treatment of objects, and it will often happen that much time and many different methods of preparation will be employed before the right one is discovered by which we may be enabled to investigate the structure of different parts with perfect distinctness. On the other hand, two observers may also arrive at the same conclusion by different methods, while each of them may consider his own mode of preparation the best.

In the first place, it must be determined whether the object is generally adapted for microscopical investigation. We do not here refer so much to those circumstances under which the microscope is not able to afford us more distinct characters than those we obtain with the naked eye; nor have we those cases in view in which the microscope affords us even less information, because the differences, which may not exist so much in the elementary parts as in their arrangement, frequently disappear under the microscope, although they may be apparent to the naked eye. We refer here to those external influences which cause objects to offer themselves to our view under conditions that are no longer normal. Now, we should make it a rule never to submit a body that is not perfectly fresh to microscopical examination, at all events not for the first examination. The observer should, of course, be intimately acquainted with the changes that are induced by the cessation of life and the influence of external agents (air, water, cold, etc.). Manifold are the errors which have crept into science, because observers have made an improper choice of their materials, and have observed and explained forms which had ceased to be normal. At the same time it must also be remembered, that whilst many parts both of animals and plants can preserve a long time, after the extinction of life, both the natural forms of the elementary parts as well as their arrangement, and may therefore serve for anatomical as well as for microscopical investigation, there are other parts, particularly of animals, in which the case is different, and in which both the form and the arrangement appear under conditions which scarcely allow us to form a conjecture regarding their natural state. I shall here only call to mind the investigations respecting the

retina, and the erroneous opinions of the structure of this organ, which for the most part arose from the improper choice of the material.

The chief rules for the preparation of objects for microscopical researches are in general determined by their consistence. Now, the purpose of the preparation is, to bring the opaque parts to such a state of tenuity, and to extend fluid bodies to so thin a stratum, that transmitted light can be used. Therefore opaque substances, which it is either impossible to make transparent, or which are only to be examined with reflected light, require no other preparation than that which is necessary to fix them upon a proper base. They should be placed upon the stage and examined in the manner we have already referred to, when we spoke of the illumination of opaque bodies with reflected light. Meanwhile it will be well, if possible, to arrange the surface of the object in such a manner that it may be plane, and that the whole surface may be equidistant from the object-piece. The image becomes clearer when seen on a glossy surface. If the body be not naturally bright, it may be rendered so by a thin stratum of water, turpentine, or some other varnish.

If, on the contrary, the object is to be observed upon a glass-plate with transmitted light, and if it possesses a moderate consistence, as thin a slice as possible should be cut from it. Some practice is required to do this, especially when the slices are to be of a certain size. Scissors are rarely used for this purpose, as they are liable to crush the parts. It is better to use a common sharp knife, or one with a broad blade, when larger pieces are required; a sharp razor can also be used, both here and on other occasions. Valentin's double-knife may be useful for cutting large slices, which the observer may intend to keep; in general, one may cut with greater facility with a common knife. In order that the piece may become more easily loosened from the knife, a drop of water must be put on the object, or the knife dipped in water; at times it will even be necessary to make the whole section under water. If the object be very small and delicate, and difficult to hold with the fingers, it can be laid upon a thin piece of cork, or it may be fastened upon it, and both be cut together; the pith of the elder-tree or of a goose-quill can also be employed. Oschatz's microtome would be convenient for obtaining a great number of uniform

pieces, if this instrument were not so complicated and costly. Pappenheim uses a plane to obtain very long pieces; by continuous planing he divides the body into a number of thin shavings; but the object must be hardened in a solution of carbonate of potash or in creosote, of which we shall speak presently.

If the substance be so hard as to render it impossible to cut it with a knife, a file or grindstone must be used. One side of the piece must in this case be rendered perfectly smooth, and then be fixed tightly with gum or wax upon a block of wood, and the other side reduced with the file or grindstone. During this operation, the best mode is to fasten the substance on a glass plate, in order the better to watch it with the eye, and to notice when it becomes sufficiently thin to be illumined by the transmitted light. The gum or wax may be dissolved by placing the preparation for a time in cold water. The whole piece should, in most cases, be of uniform thickness; but it may occasionally be cut thinner in some parts than others, in order the better to show the arrangement of the elementary parts. The pieces should be cut in different directions, both longitudinally and transversely, so that a distinct image may be obtained of the elementary parts of the object, and their mutual position, either on regarding them *en face* or *en profile.*

If, finally, the object be very soft, so that it does not admit of being cut in sufficiently thin layers, a suitable thinness can be obtained by compressing a small portion of it; and in this case either a compressorium may be used, or the object may be covered with a thin glass plate, which should be lightly pressed, by means of a needle, against the glass plate upon which the substance lies. The object is sometimes so soft, that the pressure of the thin glass plate is sufficient to produce the necessary thinness and transparency. If it is feared the pressure may be too heavy (as, for instance, on observing the motions of infusoria in a fluid), or if the observer wishes to see a thinner or thicker layer of the object, a fine hair, or another very thin substance may be placed between the glasses, at a greater or lesser distance from one of the edges; the substance thus interposed prevents too strong a pressure. If the elementary parts are in a fluid, preparation is rarely if ever necessary, and a small drop of the fluid need only be placed upon a glass plate, and covered with another and thinner glass plate, in order, by means of a stronger or weaker pressure, to exhibit it as a transparent pellicle.

It may occasionally be expedient to harden the substance, in order the better to be able to cut portions of the softer parts. For this purpose, alcohol, creosote, carbonate of potash, and especially much-diluted chromic acid, may be used. The chromic acid causes the elementary portions to separate much more easily on preparing them with needles, and causes them to appear more distinct by their becoming coloured yellow. Most animal substances preserve the form of their elementary parts unchanged in diluted chromic acid, and many indeed appear even more distinctly than in their natural state; this agent is therefore particularly useful for the preservation of objects to be examined with the microscope. Another mode of proceeding consists in drying the whole body, and then removing from it fine slices, which must afterwards be softened in a fluid before they are submitted to observation. Other parts can be previously macerated, or boiled, or operated upon with chemical agents, as, for example, with ether or turpentine, in order to extract the greasy particles; with muriatic acid, to dissolve the lime; with acetic or iodic acid, to bring the nuclei of the cells into view; with sulphuric acid, to show the epidermis of hairs; with iodine, to detect the globules of starch; or with indigo or carmine, to observe the alimentary canal in infusoria. Transverse sections of hairs can be procured in shaving, or by fixing the hairs in a fissure (as in a brush), and then cutting them transversely, etc. Every observer must, however, employ the method he finds most applicable, as, under similar circumstances, one plan may be resorted to by some persons in preference to another requiring greater attention. Thus, for instance, it is easier to procure a thin plate of the ethmoid bone, in order to observe the bone-corpuscles, than to make à preparation from a larger bone; and so forth. We cannot here enter into a description of the effects of chemical agents in general, but must refer our readers to chemical works.

It is often sufficient to form fine slices of most parts of plants, and many of those of animals; but the greater number of animal substances require a different procedure, especially when they are either so tender or so tough as to render it impossible to obtain fine slices from them. In such cases, a small portion of the substance should be placed upon a glass plate, and divided, by the help of a sharp-pointed knife, or with a needle, into the smallest portions possible. The effect of this is to separate and isolate the elementary

parts, whilst, at the same time, larger pieces can be better observed in their relative arrangement when so divided. This preparation is sometimes made under a magnifying glass.

It is necessary to add a fluid before examining slices or fragments of a substance. One great object of this is to prevent the desiccation of the substance by evaporation ; the elementary parts besides, become separated during the preparation, so that they do not cohere with each other or with the glass plate, but become moveable and swim freely in the fluid; the surface of the body is at the same time rendered smooth, and receives a kind of polish, while it gains more transparency, and its contours acquire sharpness. It is only when it is desirable to show the object with stronger outlines, or when the fluid may make the parts too transparent, that the latter is dispensed with in the observation. When the elementary parts already exist in a fluid, it is usually unnecessary to add another fluid, unless their number be so great that the whole field of view would become covered by them, and their free movement be obstructed.

As most parts of animals and plants contain water naturally, this fluid is in general made use of. Distilled water is best, but clear pure spring water is usually sufficient, as it does not often contain foreign solid substances, such as infusoria. These may, however, very easily disturb the observation, when they swim round the preparation.[1] Warm water is seldom required.

In many cases the addition of water is not injurious to the elementary parts ; in others, on the contrary, they suffer materially from the absorption of water, which alters their structure, or even dissolves them. Other fluids, the effect of which can be better borne by certain substances, have been, therefore, used as common attenuating or diluting media. We may instance solutions of common salt or sugar; also the white of egg, the serum of the blood, the fluids of the eye, diluted acids, especially acetic and chromic acids, diluted alcohol, especially when the substance has already been preserved in it; finally, creosote, oil, and turpentine. The latter is applied particularly in the case of dry substances ; for example, teeth,

[1] It is a mistake to suppose that a drop of water contains many thousand infusoria; by this expression it is only meant that these animalculæ are so small, that such a multitude *can* be contained in a drop of water ; but happily it is not the case in moderately good spring water, which contains extremely few infusoria.

crystals, petrifactions, but it occasionally makes the elementary parts too transparent. Saliva is improper, because it is mixed with epithelial cells and air-bubbles, both of which disturb the observation. It is clear that one cannot use such attenuating media as will dissolve the object,—viz., acids in the case of crystals, or turpentine in that of fat; nor can oils be added to a preparation that contains water, unless for some special purpose.

There are substances, for example the retina, which do not admit the addition of fluids; and may therefore be allowed to remain in the medium in which they already exist. In such cases, fluids are only added that their effects upon the elementary parts, after their normal condition has already been observed, may be ascertained.

The fluid used is generally applied before commencing the preparation of the object, with a knife or a needle. But if the substance be very tender, and there be danger that it will not well resist the effect of the fluid, it is better first to cover it with a thin glass plate, and then to take a drop of the fluid upon a knife, and holding it against the edge of the thin glass plate, let it run in by the force of capillary attraction. This mode of proceeding may also be adopted when the substance is already upon the stage, and it is desired to observe the immediate effect produced by adding more of the same or some other fluid. For the same purpose a thin cotton thread may be laid under the thin glass plate, a drop of the new fluid put upon the glass plate, and the loose end of the thread dipped in it; thus the fluid will, by the help of the thread, be conveyed to the object. Care must be taken not to add so much of the fluid as to cause it to flow over the covering-plate, which can easily happen when the latter is very thin. If too much has been applied, the objects are rendered unsteady. The superfluous fluid may be absorbed by means of blotting-paper; when the formation of crystals is being observed, the fluid should be removed by concentrating the solution. If the fluid begin to evaporate, it occasionally retreats in a curved line over the field of view, drawing all the particles with it, and there will then often remain a number of lines upon the glass, crossing each other, and sometimes in a tolerably regular form, having the deceptive appearance of ramifications or fibres.

We have already alluded to the use of thin glass plates. The object to be observed is covered with one of these, partly to prevent evaporation and preserve its moisture, partly to prevent the ob-

ject-glass being covered with vapour and rendered obscure; finally, also to produce a slight pressure, by which the elementary parts may become separated from each other and lie upon one plane, at the same time that they become fixed. In most investigations the object is covered by a thin glass plate; yet it is not absolutely necessary, particularly where a lower magnifying power is used. There are also substances that are so tender, that they cannot bear the superposition of a glass plate; whilst, in other instances, a thicker glass plate may, by its weight, compress the substance more strongly, and thus serve as a substitute for a regular compressorium. We have already spoken of the use of the latter instrument, and at the same time recommended that the superposed glass plate should not be so thick as to prevent the object from being brought into the focus of the object-glass.

On examining microscopes that are made by different opticians, it will be found that some produce a better image, when the object observed is covered with a glass plate; whilst others, on the contrary, perform better without it. Further, it will be found that some bodies under the same magnifying power are seen more distinctly, and more clearly defined on being covered with a glass plate; others again are better observed when uncovered. Indeed, on a closer investigation, combinations of object-glasses and eye-pieces will be met with, where one or other of these modes of proceeding will be found to give the best image, with an adjustment of different lengths of the tube of the microscope, and when even the varying thickness of the superposed glass plate may exert influence. This difference is partly dependent upon the fact, that the instrument-maker, whilst he combines the lenses to produce a good image, makes use, from the first, of a test-object, either with or without a glass plate cover, and then arranges his lenses in such a manner that the aberration is destroyed by one or the other of these modes of proceeding. Yet here also the peculiar properties of the object must be taken into account, although no definite rules can be given in reference to this point. Since it is expedient in most cases to cover the object with a glass plate, those microscopes which permit this to be done are to be preferred. In general, the difference between the purity of the image, when use is made of a glass covering plate, and when the object remains uncovered, is most perceptible where high powers are used.

When the object has been duly prepared, *the observation* may be

commenced. The object is to be cautiously placed upon the stage, while the observer is careful to avoid its coming in contact with the object-glass. Beginners, therefore, will do well to have sufficient space between the object-glass and the stage when the object is placed upon it. If the object-glass become damp, either from contact with the object, or by receiving moisture from it (which also must be guarded against in the progress of the observation), by which it may be rendered obscure, it should be dried immediately, or the observer must wait a few moments until the vapour disappears. The object is then brought into focus by the help of one of the above-described modes of adjusting the stage or the tube, the coarser adjustment by the rack and pinion being first used, and afterwards the more exact adjustment by the finer screw, when the microscope is supplied with one.

The eye must be brought as near to the eye-piece as possible, that a large field of view may be obtained, and foreign light excluded; yet the eye-lashes must not be allowed to come in contact with it, for fear of disturbing the observation and soiling the glass. As it is only possible to observe with one eye at a time, it is best to close the other eye, so as not to fatigue it, especially when it is held a long time open directly against the light. It will scarcely be necessary to bind anything over the eye, or to make use of the black screen upon the eye-piece already referred to. A habit should be acquired of observing with both eyes, and of using them alternately, otherwise the power of sight easily becomes different in the two. The observation must never be continued so long, or with so bright a light, as to occasion weariness of the eye.

The movement of the rack or of the screw must be made with delicacy, but with a firm yet light hand. It is, therefore, best to support the elbow upon the table before which one sits, or to hold the arm against the body when standing. When sitting, the breast must not be supported against the table, lest the pulsation of the heart against it should interfere with the observation. It is well here, as on other occasions, to acquire the practice of using both hands; the handles of the screws, with which the movements are made, are generally, however, placed on one side only, and then the other hand is used to move the object under the object-glass, and to regulate the reflecting mirror and the diaphragm. During the observation, the screw-handle should be constantly held in one hand, that

there may be no interruption whilst performing the small movements that are necessary for observing the edges and surface of the object, and for examining any other body in the same field of view, but not in the same focus. The observer must avoid bringing the object-glass and the object observed so near together as to come in contact, or even when the object is covered with a glass plate, to strike each other with so much force as to injure or break them. This happens very easily, if attention be not paid to the direction in which the screw turns, or if it be turned too quickly. The nearer the object-glass and the object come together, when brought into focus, so much the more slowly and carefully should the screw be worked. Care must also be taken during the observation to ascertain the shortest distance at which it is safe to place them. Caution must particularly be used with the more powerful object-pieces, where the focal distance is very short.

It must be borne in mind that the image is inverted, and that consequently the object is moved in the direction contrary to that of the image, unless a prism has been placed upon the eye-piece, by which the image is erected,—this apparatus is however but seldom used, and it is easy to accustom one's self to the inverted movement. In order to move the object under the object-glass, the moveable stage is most suitable, although it may be dispensed with. Whilst the object is being moved, it must never be lifted up from the stage, but must only be made to glide upon it, to escape contact with the object-glass. For instance, it is necessary to move the glass plate upon which the object lies backwards and forwards upon the stage, in order to seek the object, and to see the elementary parts under as many forms as possible. As it is desirable to have an opportunity of observing the elementary parts of the object from all sides, they should be suffered to float in the fluid, by which their consistence will be ascertained, when they come in contact with each other or with other bodies. This can be done by setting the whole mass in motion, or striking the glass plate gently, or by adding or subtracting a little of the fluid, whereby they will be set in motion. If the preparation be not covered with a glass plate, evaporation also occasions motion, which will be proportional to the rapidity of the former. In the meantime, the observer should not be deceived by the motion of the parts, for it may also arise from the presence of infusoria or vibratory cells in the fluid. One also soon discovers, by constant inclination of the parts

towards one side, whether the stage be horizontal or not. If we want to observe at once the combined and the isolated elementary parts, it is best to notice the edge of a fragment. Now and then, also, it will be proper to use pressure to make the object more transparent.

There is no intrinsic difficulty in simply viewing an object through the microscope, although it is different when an examination is to be made for the purpose of giving an *explanation* of what is observed. The difficulties here chiefly depend upon the manner in which objects are illuminated on applying transmitted light. It is far easier to observe and explain the nature of opaque bodies, which are viewed with reflected light, because the light comes from above from the one side, and the shadow falls upon the opposite side, in the same manner as the naked eye generally sees objects with reflected light. The colours also of bodies, which render their recognition more easy, remain unchanged under reflected light. With transmitted light, which is used in the great majority of examinations, the colours of objects, even when strong, are easily lost; the whole relation of light and shadow is changed; and great practice is often required to decide whether the body under observation is solid or hollow—whether it is a hollow or a solid cylinder, or a flat long band, a stripe or fibre, a globule or a round plate, an aperture or a spot, an elevation or a cavity, and so forth. The reason that we cannot perceive such differences at first sight, is chiefly because, on looking through the microscope, we only see that plane of the object with perfect distinctness which is exactly in the focus of the object-piece; whilst a plane of the object, which is at a nearer or a greater distance, is misty or indistinct. Whilst the power of accommodation inherent in the eye ordinarily assists us in the alternate observation of nearer or more distant bodies, it fails us in microscopical observations, and its deficiency can only be compensated, when, by moving the lenses to and from the object, we bring different planes into focus. Where, as in many cases, it is difficult to distinguish, at any considerable distance, a bas-relief from a picture with the naked eye, we avail ourselves of the varying position of the eye, a nearer approach to the object, or the sense of touch, when the resemblance is very great, to decide the point; but these means fail us in microscopical observations, and are only imperfectly compensated for by the alternate stronger or weaker illumination of the

object. Finally, the explanation is rendered difficult by the peculiar mode (diffraction) in which transmitted light (by the so-called interference of the rays) is deflected round the edges of bodies, so that they appear to be bordered by a fine white fringe, which, in a round body for example, may be taken for a light pellicle, or in a long body for a circumjacent tube, or may induce the observer erroneously to attribute a double contour to an object. Diffraction is stronger when strong object-glasses are used, and especially when the transparent bodies having sharp outlines are examined; it causes less confusion with weak object-glasses and with more opaque bodies; it becomes also stronger, when the object is not exactly in the focus, but disappears on changing the position of the reflecting mirror. I have remarked, that diffraction is stronger with some microscopes than with others, without being able to discover the cause with certainty; it is possible that it arises from the greater or lesser aperture of the object-glass. The fine white line becomes iridescent, when, instead of common daylight, the direct light of the sun, or of a powerful lamp, is used. An ignorance of the laws of diffraction occasioned numerous errors amongst the earlier observers, particularly in investigations conducted with direct solar light, and its consequences may be traced even in delineations by more modern authorities.

These difficulties, in the explanation of the observation, may indeed be lessened by the application of the above-mentioned rules, for the preparation and the observation, and by attention to the last-named causes; but it is only by a steady and long-continued observation and practical dexterity that they can be entirely removed. The readiness with which this faculty of interpreting observations may be acquired, will depend in great measure upon the individual powers of the observer. A healthy eye is the chief condition; but it must be associated with a taste for form, and with a ready perception of its modifications; for it is only by the combination of such powers as these, that a clear and exact idea of an object is obtained. The visual sense follows the same rules as the sense of hearing; it is one thing to be able to hear tones, but it is another to comprehend them, combine them, and give them utterance in the form of melody. The resemblance between these two senses goes no further; for the visual sense is the only one which mankind hitherto has been able to heighten; and we are as yet unacquainted with equally admirable expedients for remedying defects of the ear. The increased powers

of the sight have, however, led to the inconveniences which we have mentioned above; but it is only when we neglect the consideration of this point, that the microscope can give rise to optical illusions. The observer should be very cautious not to ascribe to the microscope errors which are solely due to his own want of care and precision. Among such causes of error, we may mention greasy streaks upon the lenses, or scratches upon the glass plates, occasioned in preparing the object with needles, or streaks upon the object where it has been cut by a file or a grindstone, especially when the body is of a fibrous structure or a streaky surface; dust on the lenses or glass plates, which, together with particles from the cloth used in cleaning, may be mistaken for parts of the substance about to be examined; and, lastly, the oxide of iron employed in polishing, or the air-bubbles in the glass plate, etc. To ascribe the effects induced by such causes as the above to the instrument, would be much the same as if any one, during a stethoscopic examination, were to confound the friction of the clothes with crepitation. If an observer is incautious enough to be over hasty in the publication of such observations, he betrays a want of accuracy, and an excessive confidence in his own powers, which he ought to have strengthened and tested, by commencing with the examination of easy and familiar objects, and afterwards proceeding to newer and more difficult ones. It is to the wrong explanation of observations that the greatest number of errors must be attributed, as well as the discredit that attached for a time, and not without cause, to microscopic observations. This state of things has, however, been changed, not only by the increased perfection of instruments, but also by the better instruction of observers, and by the greater industry and carefulness which are required to attach scientific importance to a microscopical observation, or to impart to it more than a mere historical significance.

Among very common occurrences, which may disturb the observation, but will hardly lead to an improper explanation, we will briefly allude to two causes of error, in addition to the frequent intermixture of small and large air-bubbles in the preparation, which particularly attract the attention of beginners, but soon become familiar. The former of these is the presence of the so-called "*muscæ volitantes*," with which many persons are affected, and which frequently disturb an observation. These are in general

round molecules, which are either grouped together, or collected like rows of pearls with different curvatures, and which incessantly come before the eye. As, however, the figure which shows itself in the field of view is continually the same, it is easy to distinguish them from the substance under observation, and likewise from the grains of dirt which may happen to be upon the lenses; the situation of the latter can be discovered, as before mentioned, by turning the eye-piece or object-glass. Another common microscopic phenomenon is the molecular motion, originally described by Brown. It consists in this, that all small particles existing in a thin fluid show a constant and spontaneous motion, which becomes stronger in proportion to the minuteness of the particles. The magnitude of the bodies that possess this movement varies (to choose familiar objects for comparison) from the size of the molecules of the black pigment in the eye to that of the human blood corpuscle. The movement is either tremulous or circular, at other times altogether irregular, so that a molecule can pass over a greater or lesser extent of the field of view; it is more oscillatory when the particles have some length. The movement may be so powerful as to influence larger bodies. It is self-existing, and does not arise from evaporation; for the movement produced by the latter is far stronger, the particles being thrown indiscriminately together, and the appearance being often that of a boiling fluid. The molecular motion, on the contrary, is seen to be equally strong, even where evaporation is prevented,—when, for example, the fluid containing the molecules is surrounded with an oil, or contained in a sealed glass tube; yet it is said to become stronger when the fluid is warm; but light, electricity, magnetism, and chemical influences, produce no effect upon it. It continues uninterruptedly for many years in hermetically sealed preparations.

We have only briefly noticed amongst the accessory parts of the microscope the apparatus for *measuring* and *delineating* objects, deferring till the present time all further instruction in reference to their uses. We therefore now proceed to the exposition of their use,—purposing, in the next place, to add some remarks upon the *preservation of microscopic preparations.*

a. *Of Micrometry.*

In order to define the nature of an object, its magnitude must also be taken into consideration. In general, the magnitude of objects visible to the naked eye is decided by comparison with a fixed measure of feet, inches, and fractional parts; for microscopical objects the scale of measurement must also be microscopical, and hence a special apparatus has been invented for such estimates. The methods employed for measuring microscopical magnitudes are embraced in the term "micrometry," and are conducted by means of different instruments. Micrometry includes the measurement of the object observed, and takes account of the number of times it is magnified, the two computations being closely connected with one another.

In former times, *the measuring of microscopical objects* was performed by comparison with other small objects, as with the thickness of a hair or of the spider's web, with Lycopodium dust and the sporules of Lycoperdon Bovista (puff-ball), or with grains of sand (Leeuwenhoeck), of which a hundred were contained in an inch. Jurin made use of sections of small pieces of silver-thread, of which a certain number of circumvolutions round a needle composed an inch. It is self-evident that these modes of measuring were far from giving exact results.

Wollaston and Goring constructed two micrometers, which can only be partially applied to the single microscope, and which consist of parallel wires or hairs, which are placed behind the object, so that during measurement it appears to rest upon them, and its magnitude is determined according to the previously settled length and distance of the wires or hairs. But these micrometers, as well as Dolland's wool-meters, which can only be used with the single microscope, are no longer employed with the compound microscope.

Dolland's micrometer consists of the two halves of a lens, which show the object single when both the halves lie closely against each other, but make it appear double when they are separated. With the help of a scale, or a micrometrical screw, the distance at which the two halves of the lens are situated when the object is seen double can be measured, and in this manner its breadth is ascertained.

The so-called point-micrometer is now likewise out of use. It was invented by Martin (1740), and consists of an eye-piece, into

which two needles are introduced, placed diametrically opposite to each other. In order to measure an object, the points are screwed so far out that they touch the edges of the image of the object. The distance between the points is then measured either by means of a glass micrometer, or of a micrometrical screw placed upon the head of the needles. Very small objects cannot be measured in this manner; larger or opaque substances may be measured with considerable exactitude, and it is now applied as a wool-measure.

The micrometers now in use are the screw micrometer and the glass micrometer.

The idea of *the screw micrometer* (Pl. I., fig. 12), first constructed by Frauenhofer, is taken from the point-micrometer. It is, indeed, as we have already seen, only a moveable table. It consists of a plate, screwed firmly upon the stage; another plate is laid upon it, and can be moved from one side to the other by a very fine screw, of which a certain number of revolutions are performed within the tenth part of an inch; we will, for example, assume their number to be ten. Now, if the screw be turned ten times round, the upper plate moves $\frac{1}{10}$th of an inch from the one side to the other, consequently $\frac{1}{100}$th of an inch in one revolution. The head of the screw is on the edge divided into a hundred equal parts; for every such part the upper plate moves $\frac{1}{10000}$th of an inch; and as the head rests against a vernier (a small ruled plate, of which ten parts are equal to nine parts of the division of the head), one can shift the plate $\frac{1}{100000}$th of an inch from the one side to the other.

In order to use the screw micrometer an eye-piece must be employed, upon the diaphragm of which a fine thread of the spider's web is extended. Instead of a thread, a strip of glass, upon which a fine line is drawn with a diamond, may also be used; it is laid upon the diaphragm, but the line is often not distinctly visible, especially when the illumination is very strong. The thread is so placed as to form a right angle with the screw of the micrometer, which is done either by turning the whole eye-piece, or by a distinct movement of the diaphragm in the eye-piece. The object is laid upon the upper plate of the screw micrometer, and the portion to be measured is placed in such a position as to cause its image to appear in contact with the thread. Now, by moving the screw, the upper plate shifts its position together with the object, and the screwing is continued until the image of the object is found to be upon the

other side of the thread. The number of the revolutions of the screw will then indicate the diameter of the object. The complete revolutions are enumerated upon a separate scale applied to the upper plate, whilst the head of the screw shows the single lesser parts. If, for example, a whole revolution has been made, and the head turned through five parts of the scale, the breadth of the object is equal to 0,01 + 0,0005 of an inch. The calculation would thus be very simple, if ten revolutions of the screw composed exactly the tenth part of an inch, but unfortunately such is not the case. For, in the first place, it would scarcely be possible to make such delicate screws; and, in the second, it is equally impracticable, when we have to do with the ten-thousandth part of an inch, to prepare the screw in such a manner that one revolution shall precisely constitute a round number. It is, therefore, necessary to calculate, by means of a glass micrometer, the value of one complete revolution, and subsequently determine the fractional parts. Hence we have estimates of magnitudes with very small fractions, which render the calculation extremely difficult. If the screw micrometer, therefore, be frequently used, it is best to note down in the form of a table the value of one or more parts of the screw, so that one may see immediately to how much a certain number of revolutions or parts of these amount. The calculation also becomes more involved, as it is not possible always to begin the measurement from the zero of the subdivision of the head, because one cannot always so place the object that its image shall appear at the side of the thread; this is particularly the case on measuring many objects successively. However, this inconvenience has been obviated by making the scale upon the head of the screw moveable, so that the zero can be fixed at will, while the scale on commencing the measurement is fastened to the handle of the screw with a separate screw. Further, with a view of bringing the object into a position parallel to the wire, a disc, moving upon its own axis, has been inserted upon the upper plate of most screw micrometers, and upon this the object is laid; whilst, by applying screws to the front and side edges of the plate, the object can be moved backwards and forwards, and from side to side, in the same manner as upon the moveable stage. All these expedients are necessary to get the object to lie in a position suitable for its measurement, which even then is difficult enough at times. There is also the inconvenience con-

nected with the use of the screw micrometer, that it must either be attached to the stage whenever the measurement is to be made, or must remain fastened to it; but in the latter case it may easily happen that it always becomes used as a moveable stage, which causes the screw quickly to wear away, and thus destroys the precision of the instrument. Besides this, in drawing the object it will be necessary to have a separate apparatus.

There are, moreover, several more important reasons, which, besides the expense of the apparatus, oppose its general use. In the first place the screw presents the same defect as all other screws, and, notwithstanding the very great care employed by opticians in its manufacture, these defects cannot be altogether remedied, and naturally increase the more the screw becomes worn. It is therefore necessary, before commencing the measurement, to turn the screw once round, in order to be quite sure that it takes hold in the female screw, and the observer must remember always to screw in one and the same direction; for example, from right to left. If the screw were turned from left to right, in order to bring back the image of the object upon the other side of the wire, or to repeat the measurement, one could not be certain that the screw had duly taken hold; in screw micrometers that have been much used, it may at times be observed that the upper plate does not move as soon as the observer begins to turn. Schiek and Plössl have endeavoured to obviate this defect, by applying a strong spiral spring, which presses the upper plate backwards, and by which the screw is pressed fast into the box. Furthermore, we cannot depend upon the threads of the screw having everywhere the same breadth; experience confirms this in part, and the screw micrometer must therefore be tested in several places with the assistance of a very accurate glass micrometer before it is used. In the next place, the measurement may become incorrect through the elasticity of the stand or the stage, when too firm pressure is made upon the screw, so that a side movement may arise, which does not depend upon the turning of the screw; this will especially be the case if the stage be not very firm. Finally, diffraction makes it often difficult to place the object in such a manner that the image shall be formed by the side of the thread in the eye-piece both before and after the measurement. The smaller the body is, the more important will be the error which arises from one of the above-named causes, the greatest number of

which, as will be seen, are to be imputed to the mechanical imperfection of the apparatus, whilst the last-mentioned only—namely, diffraction—depends upon the optical construction of the microscope. We shall now see that the glass micrometer merits preference, both on acount of the greater accuracy of measurement of which it admits and of its more convenient application.

The *glass micrometer* (Pl. I., fig. 13) is a glass plate, upon which a microscopical scale is graved. A millimetre, or a tenth part of an inch, is generally divided into a hundred equal parts, which are marked upon the glass by means of a diamond, fixed in a machine for the purpose. The divisions are sometimes, however, either larger or smaller. The strokes are parallel, and each fifth and tenth stroke is drawn longer than the others, for facility in counting. Other glass micrometers are divided into squares; but this mode of division is not so good, on the whole, because the glass easily springs in the angles where the strokes cross each other, and because the great number of fine lines may at times mislead; these glass micrometers, therefore, are mostly used only for the measurement of larger objects. The subdivided glass plate is of various sizes, and can be enclosed in a brass ring or plate, that it may be the less exposed to injury. As the place on which the fine division is marked upon the glass plate is almost invisible to the naked eye, it may be seen better by surrounding it with a coloured ring, which enables the observer more readily to find it under the microscope.

There are various modes of using the glass micrometer. The simplest is, to lay the object upon it, and then to count how many parts of the scale it occupies. Yet this method is not generally used. For, on the one hand, the object and the division of the micrometer do not always lie upon the same plane, and cannot be seen distinctly where they are not in the same focus; while, on the other hand, the object cannot at all times be laid in a position suitable for measurement, so that an approximate estimate is frequently all that can be obtained, and such is also the case with objects that are smaller than one part of the scale. Besides, as one cannot always previously know whether it will be necessary to measure the object at all, the glass micrometer must constantly be used as a common glass plate, and care must be always taken that the object shall lie exactly upon the division. As, however, the preparation of the object with pointed needles, and the frequent polishing of the

glass, very quickly spoil the micrometer, the scale necessarily becomes indistinct. Opaque objects can never be measured in this manner, because they conceal the division. This method, therefore, at the utmost, can only be applied for measuring larger and more transparent objects, magnified with low powers. A better mode of using the glass micrometer is by applying it to the eye-piece. It is laid upon the diaphragm with the divided scale turned downwards against the field glass, so that it is placed exactly in the focus of the eye-glass. Another glass micrometer, whose mode of division is known beforehand, is laid upon the stage, and the observer notes how much one part of the last-named glass micrometer (which is enlarged by the object-glass and eye-piece) amounts to, in comparison with the glass micrometer placed in the eye-piece, and consequently only enlarged by the eye-glass. A certain proportion is then found between both glass micrometers, and every observer must afterwards calculate for himself a table of the value of the single portions of the glass micrometer which is in the eye-piece. But difficult calculations easily arise in this manner; and there is besides this the inconvenience, that the glass micrometer must be put into the eye-piece each time a measurement is made, or the observer must keep a separate eye-piece in which it is fixed, and which therefore must be applied whenever it is to be used. Further, it often happens, as with the foregoing method, that the measurement of parts of an object which do not exactly answer to one single division of the glass micrometer, must be calculated merely approximatively; it is difficult at times to perceive the divided scale when it is very delicate; the greater breadth of the strokes of the diamond may at other times be a hindrance in measuring the object with due exactness, because it cannot be decided whether the edge of the image is or is not exactly covered by the stroke. We have, however, this advantage over the former method, that the micrometer does not require to be so finely divided, and that errors in its division are of less consequence, because each single part has a smaller value than when it is enlarged by the eye-piece and object-glasses. Further, more opaque bodies can be measured; for the divided scale is placed before the object, and it is easier to fit the image of the object to the strokes, because the eye-piece can be turned round upon its axis. The object must lie in the centre of the field of view.

The glass micrometer is most conveniently and easily used when

its division is compared with that of some measure in common use. Hooke, who used this method, laid a measure upon the table by the side of the microscope, and with the one eye watched the object, and with the other observed how many parts of the measure it occupied. It is, however, trying to the eyes to observe two separate objects at the same time, in order, by means of double vision, to cause the image of one to rest upon the other. But since different instruments have been invented by the help of which objects may be delineated, and of which we shall hereafter speak more fully, this method has been rendered more simple. Thus, for instance, it is only necessary to prepare a magnified scale, in order to measure the magnified object; and this is done by delineating some portions of a glass micrometer—for example, some hundred parts of an inch or of a millimetre, with a given magnifying power, and at a certain distance of distinct vision. The contour of the object is then

Fig. 17.

drawn, under the same magnifying power, be it remembered, and at the same distance of vision, when it may be measured by the help of a pair of compasses in all directions with the scale upon the paper. It is quite immaterial to know the magnifying power employed, which always varies somewhat before the eyes of different individuals, because to short-sighted persons objects appear less magnified than to those who are long-sighted. But, on the other hand, it is for the same reason necessary that each one should draw the scale and the object for himself; the distance of vision may, as already observed, be made greater or less, provided the same distance of vision and the same combination of eye and object-glasses be employed for delineating the object and the scale.

If it happen that the object is smaller than one of the delineated parts of the scale, the scale upon the paper must be divided into as many smaller parts as may be found serviceable. A glass micrometer with finer divisions may also be applied, or a greater distance of distinct vision be used for delineating the parts of the micrometer on a larger scale; for it is easier to divide a larger than a smaller portion, and also easier to measure the object when it is delineated

on a larger scale with an increased distance of vision. Care must, however, be taken not to carry this mode of procedure too far, because the sharpness of the contour of the object is easily lost where the distance of vision is disproportionally great. The scale also may be fixed beforehand, and the distance of vision be sought for, at which it corresponds with the division of the glass micrometer; for example, this can be done when the observer wishes to use the same scale that has been adopted by some other person. Although, as we have already observed, the distance of vision is here immaterial, when the scale and the object are only delineated at the same distance, it is better at all times to employ a fixed distance of vision, and we have therefore already adopted a fixed distance of $0{\cdot}25^{m}$. Scales should, therefore, be drawn at this distance for each separate combination of the eye and object-pieces of the microscope, and the object drawn at the same distance. If this plan be followed, nothing further is necessary but to measure the object with the compasses, and this can be done in all possible directions, without any confusion arising from the position of the object; nor is it necessary to make any calculation, as in the foregoing methods, to which this mode of proceeding is infinitely preferable. It is applicable in a precisely similar manner to the simple, the solar, and the oxyhydrogen microscope. It must be evident from the above observations, that the magnitude of the field of view may be measured by any one of these methods, either with a glass or a screw micrometer placed upon the stage, or by delineating the whole field of view.

One precautionary rule must absolutely be observed in this mode of procedure. It is obviously requisite to use a glass micrometer that has been divided with extreme precision; and this, as we shall see, is not the less necessary when the same method of proceeding by the delineation of the micrometer or some other object of known dimensions is employed to determine the degree of magnifying power. As, for instance, the glass micrometer is divided by a delicate screw, of the imperfections of which we have already spoken, the objection may justly be advanced against it, that all the defects of the screw are transferred to the glass; and, indeed, we actually find that not only do glass micrometers, made by different instrument-makers, not correspond to one another, but that even the separate parts of one and the same glass micrometer are not of equal size, when they

have been transferred to paper, which is the only sure mode of testing them. The reason of this depends partly upon the imperfection of the workmanship, and partly on the circumstance that, when similar portions of the scale are being delineated, they are not laid accurately upon the same spot of the field of view; for spherical aberration never becomes so sensible as when one and the same part of the micrometer is delineated from the image, which at one time is seen upon the edge, at another in the centre of the field. Moreover, an influence must necessarily be exerted by the eye employed in the measurement, when the distance of distinct vision of both eyes is not equal in the same individual.

The influence of spherical aberration may be decreased by limiting the field of view during the measurement, by placing in the eye-piece a diaphragm with a very narrow opening. This is particularly applicable in estimating the magnifying powers of the microscope, which we shall at once proceed to consider. This precautionary rule is less necessary in the drawing and measuring of greater bodies; but the periphery of the field of view should be used as little as possible—a remark that applies both to the observation, and more particularly to the measurement.

In order, therefore, to guard effectually against this objection, the observer must first test the accuracy of his glass micrometer by delineating every separate part (or five parts at a time) upon the paper, only choosing the image which is precisely in the centre of the field of view, when he can examine their relative exactness; and next, in delineating an object, he ought always to subjoin the scale by which the object has been measured, that others also may be able to examine the measurements. It is, then, unnecessary to mention the magnifying power or the distance of distinct vision.[1]

In addition to the micrometer of Le Baillif, I may also mention the *goniometer*, the first idea of which was suggested by Raspail. It serves to measure the angles of microscopical crystals, and consists of an eye-piece, upon the diaphragm of which there is fixed, in the focus

[1] In order to illustrate the above by an example, I will detail my own mode of proceeding. I use, in my investigations, a microscope made by Charles Chevalier at Paris, having a glass micrometer, consisting of a millimetre divided into a hundred parts. In determining the magnifying power of a certain combination of an eye-piece and object-glass, I found, on examining the accuracy of its division, with a constant distance of vision of 250 millimetres, the following values

of the eye-lens, a glass plate, upon which a fine line is drawn with a diamond. Parallel with this is laid a face of the crystal, and the angle

for every five parts, or for 0·05 millimetre, when I brought them exactly into the centre of the field of view.

Number of Parts, each ·05 Millims.	Apparent Size.		Total.	Magnifying Power.
3 corresponded to	18 millims.	=	54 millims.	indicating 360 diameters.
1 ...	$17\frac{3}{4}$ ...	=	$17\frac{3}{4}$ ...	... 355 ...
2 ...	$17\frac{1}{4}$ ...	=	$34\frac{1}{2}$ ...	... 345 ...
7 ...	17 ...	=	119 ...	... 340 ...
2 ...	$16\frac{3}{4}$ ...	=	$33\frac{1}{2}$ ...	... 335 ...
2 ...	$16\frac{1}{2}$ ...	=	33 ...	... 330 ...
1 ...	$16\frac{1}{4}$ ...	=	$16\frac{1}{4}$ ...	... 325 ...
1 ...	16 ...	=	16 ...	... 320 ...
1 ...	$15\frac{1}{2}$ ...	=	$15\frac{1}{2}$ ...	... 310 ...
20 parts or 1 millim.		=	$339\frac{1}{2}$ millims. when magnified,	

or, in round numbers, the microscope magnified 1 millimetre 340 millimetres, or 340 times. Whence it appeared, that the glass micrometer was not accurately subdivided, and that it was necessary to test the divisions. As the sum of all the parts was = 340, and as the subdivision which indicated this number was the most frequent, a magnifying power of 340 times was correctly adopted. This power, and a scale constructed in accordance with it (represented p. 72), have been used in almost all my researches. Although there is no very great difference between the power of 360 and 310 diameters, which are the extremes of the powers found with my glass micrometer, it is nevertheless necessary, once for all, to fix the magnifying power accurately for a constant distance of distinct vision. Had I made the same experiment with more powerful lenses, the difference would naturally have seemed greater.

With a view of calculating the spherical aberration of this combination, I chose the subdivision $15\frac{1}{2}$ (the extreme division upon one side of my glass micrometer), and measured the amount of amplification, when I laid that part first in the centre of the field and then on its edge. I found the amplification in the centre of the field of view = 310 (or more accurately 307), and at the edges = 315. The latter result was obtained from twelve measurements; I thrice turned the eye-piece one quarter round upon its axis, leaving the object-glass untouched, and each time took three measures at the edge of the field of view. Hence we see the importance of calculating the magnifying power from the image in the middle of the field of view; this precaution is less necessary in the delineation of objects; yet, especially when working with an instrument which is not of the best quality, the middle of the field of view should always be used as much as possible. No one will consider this amount of aberration observed in my microscope, which is the production of a distinguished artist, as at all considerable.

The calculation, by which I found the power of the above-mentioned combination = $339\frac{1}{2}$, is the result of several measurements, made on the 2d November

of the crystal is determined by the help of another glass plate, upon which a fine line is also drawn, but which can be turned round, being fastened in a moveable disc, which is divided into 360°. The lines on the two glasses are so placed that they intersect each other in the centre of the field of view, and at the point of intersection receive the image of that angle of the crystal which is to be measured. The magnitude of the angle is indicated upon the disc. The graduated disc with the appertaining plate may also be attached to the stage (Brunner), the manner of measuring being the same. This instrument is almost superfluous, when the crystal can be delineated by means of the camera lucida, in which case the angles are projected and measured upon the paper in the usual manner.

Although the indication of the distance of distinct vision is immaterial when an object is being measured with the camera lucida, it

1842, with my right eye, at a distance of vision of 250 millimetres. I did not note the number of times of measuring. I was anxious to obtain positive certainty, whether the sight of this eye, notwithstanding an almost daily use of the microscope during four to five years, had remained unchanged or not. Thus if, for instance, the eye had become short-sighted, and I had consequently been obliged to alter the interval between the object-glass and the glass micrometer in order to maintain the same distance of vision, this combination would have appeared to magnify less, because, for a short-sighted person, a given magnitude would have appeared smaller. I made, therefore (21st and 22d April 1847), four measurements with the same micrometer, with the same eye, and at the same distance of vision, and found from the mean number (339, $338\frac{1}{2}$, $337\frac{1}{2}$, $337\frac{1}{2}$), that the magnifying power was $= 338\frac{1}{8}$. The difference was, therefore, only $1\frac{3}{8}$, or the sight of my right eye during this period had become only $\frac{41}{10.000}$ths $= \frac{1}{244}$th shorter. Not only was this satisfactory to myself, but it may also set those persons at rest who are fearful lest the use of the microscope should injure the eye. M. Ehrenberg, of Berlin, also, eight years ago, communicated to me that his sight had not become changed, although there is hardly any one who has made more frequent use of the microscope. It may be advanced against the experiment I have adduced, that the temperature was not exactly the same on both occasions, and consequently that the expansion of the glass was not the same. The temperature in the room, however, can scarcely have been very different at those two seasons. I had heated the stage and the glass micrometer to between 40° and 50° C., and measured the glass micrometer at this temperature; the magnifying power calculated in the same manner was found $= 338\frac{1}{2}$. therefore very nearly equal to the calculation made at the usual temperature of the room. The coefficient of expansion of glass, is, besides, from 0° to 100° C., according to Dulong and Petit only 0·00086133. I must add, that the last measurement was made only once.

is of the greatest importance when *the magnifying powers of the microscope* are being estimated. This will appear obvious, because, as before mentioned, the degree of the magnifying power of a lens is obtained by dividing the distance of distinct vision by the focal distance, and consequently because the amount of the quotient is as dependent on the curvature of the lens and on the material of which it is composed, as on the fixed distance of vision. If, therefore, a greater distance of vision is taken than $0{\cdot}25^{m}$,—which we have hitherto assumed,—as, for example, a distance of twelve inches, the amplification will be greater; and, inversely, less when a shorter distance of vision is taken.

In order to determine the magnifying power of a compound microscope, the size of a familiar object—for example, a glass micrometer—must be compared with a common scale; and this can be done whilst with the one eye we look into the microscope, and with the other mark how many parts of the scale are occupied by the object. But it is far more convenient to draw upon paper, with the assistance of the camera lucida, some parts of a glass micrometer at the distance of $0{\cdot}25^{m}$, and then to measure how much such parts occupy upon a common scale. If, for example, five parts of a millimetre, which is divided upon a glass plate into 100 parts, are drawn upon the paper, and the result is, that the delineated scale is equal to 17 millimetres, then the magnifying power $= 340$ diameters, *i. e.*, $0{\cdot}05^{mm} : 17^{mm} :: 1^{mm} : X = \frac{17^{mm}}{0{\cdot}05^{mm}} = 340^{mm}.$

A glass micrometer is commonly used for comparison with the standard, although, of course, under the precautionary rules already indicated; but if we know the magnitude of any other object, we may equally well use that, and then obtain the magnifying power of the microscope by dividing by the actual size of the object the dimensions of the magnified image seen in the microscope, and drawn upon paper at the fixed distance of vision. Thus, with low magnifying powers, we can use an ordinary measure, and delineate a part of it with the help of the camera lucida. As the distance of vision may vary very greatly in different individuals, and constitutes a point of such great importance in calculating the power of the microscope, we need adduce no other proof of the necessity that each one should calculate the powers of the microscope for his own eye.

The power of a microscope can also be found by placing a glass

micrometer upon the diaphragm of the eye-piece, and using another glass micrometer as the object, whilst we observe how many parts the former occupies upon the latter; but in this case, as well as when we apply the same method for the measurement of an object, we must know the dimensions of one of the micrometers, or, in other words, the power either of the eye-lens, or of the object-lens + the field glass; the product of the magnifying power of both gives us that of the whole microscope. If, for example, $0{\cdot}01^{mm}$ or one part of a glass micrometer under the object-glass answers to $0{\cdot}3^{mm}$, or 30 parts of the glass micrometer in the eye-piece, the magnifying power of the object-lens + the field glass is 30 times; this magnifying power is multiplied by that of the eye-lens to obtain the power of the whole microscope.

If we wish to determine the power of a single lens, for example, of an eye-lens, a glass micrometer is placed in its focus, and the magnifying power is measured at a distance of vision of $0{\cdot}25^{m}$ by means of the camera lucida in the manner already described. We can also measure the power by dividing the distance of vision by the known focal distance, or rather more correctly by the formula, $x = \frac{f}{p} + 1$.[1] With lenses of long focus, the power is found by causing an object to form a distinct image of itself upon a wall, and then measuring the distance of the lens from the object and from the image, multiplying these distances together and dividing the product by the sum of the distances. Or we collect the direct (parallel) rays of the sun in a point behind the lens, and then measure the distance of the image of the sun from the lens. Lenses of short focal distance cannot, however, be measured exactly in this manner; but in this case either a peculiar apparatus is used, or the lenses are compared with others, of which the magnifying power and the focal distance are known, whilst they are used as object-glasses in a microscope, the power of the eye-piece of which is also known. When we know the magnifying power of a lens, the focal distance can be measured accordingly. If, for example, a lens magnifies 11 times $= \frac{f}{p} + 1$, we find $p = 0{\cdot}025^{m}$, the distance of distinct vision f being $= 0{\cdot}25^{m}$. Here also we have evident proof of the

[1] We suppose f to indicate the distance of distinct vision, p the focal distance of the lens, and x the magnifying power sought.—*Trans.*

importance of determining the distance of vision in indicating the magnifying power. When we speak of microscopical amplification, it is always in reference to a linear measurement; superficial amplification is obtained by squaring the number of diameters: thus, a body that is magnified 1000 times will have a superficial amplification of $1000 \times 1000 = 1,000,000$.

There is a great want of uniformity in the measurements used in micrometry, and the modes in which they are denoted. Every nation uses the standard that is employed in common life: thus, the French calculate microscopical magnitudes in millimetres; the English in English inches; the Austrians in Viennese lines. The fault of this rests in part with the instrument-maker, who prepares the micrometers after his own standard of measurement, and consequently forces its use upon observers. Besides this incongruity, there is another which arises from some observers using the decimal, others the duodecimal system; and those who use the latter, at times express the magnitudes in fractions of which the numerator is sometimes 1, at others times an arbitrary number. Hence it follows that we see different numbers together which indicate the same magnitudes, without being able at first sight to recognise their identity. It is easier for the eye to compare decimal magnitudes, which are also more convenient for calculation; but as long as division by the "mètre" is not more universal in common life, fractions with 1 as numerator, and three, or at the most four, numbers as denominator, will be easier to impress upon the memory, because they are more consonant to the manner in which magnitudes are in common life expressed. The greater prevalence of the decimal system, which we may hope for, may at some future period lead to greater facility in expressing and in remembering microscopical decimal magnitudes; but I could scarcely venture at present to propose the universal adoption of the division by the "mètre" in micrometry.

In order to facilitate the reduction of microscopical magnitudes from the standard of one country to that of another, I have constructed a table (Tableau micrométrique pour servir à la comparaison et à la réduction des diverses mesures, qui sont employées dans la micrométrie microscopique, 1842) in which are exhibited in five columns the millimetre, the French, Austrian, and Rhenish line, together with the English inch. The principal numbers are con-

tained in the table as given below: the magnitudes in the horizontal rows are equal.

Millimetre.	Paris Lines.	Vienna Lines.	Rhenish Lines.	English Inch.
1	0·443296	0·455550	0·458813	0·0393708
2·255829	1	1·027643	1·035003	0·0888138
2·195149	0·973101	1	1·0071625	0·0864248
2·179538	0·966181	0·992888	1	0·0858101
25·39954	11·25952	11·57076	11·65364	1

Finally, we have only to add, that as the measurement of an object is to be regarded as part of an observation, it should be conducted in general accordance with all the rules already given. In order to estimate the magnitude of elementary parts, which is apt to vary considerably, a series of measurements must be made, and the mean number deduced from them, or the maximum and minimum of the numbers must be indicated, as well as the number expressing the mean magnitude which most frequently occurs. We cannot of course give any direction as to the number of measurements an observer should make in order to determine the size of any given object, nor can we indicate the number of observations that are proper in investigating an object in general; a mere statistical mode of proceeding would here be of little avail.

b. *Of the Delineation of Objects.*

By being able to delineate the objects we examine, we have not only the advantage of making the observation more intelligible to others, but we also compel ourselves, as it were, to observe with greater precision, because the delineation controls both the observation and the explanation of it. The microscopical observer, therefore, will do best to draw the object himself; a stranger will not always introduce that into the delineation which it may be desired to express, and this applies no less to the outline than to the finishing of the drawing, when the observer may wish some one special mode

of shading employed. If the measurement of the object be at the same time made by help of the drawing, it is indispensable, in reference to the various limits of distinct vision, that the observer himself should at least trace the contour of the object. As several pieces of apparatus have been invented, by which even a beginner may draw the contour of objects readily and quickly, there is the less ground for neglecting this practice. The finishing of the drawing can be afterwards effected without any fixed rules, and therefore can the more readily be left to a stranger. The drawing is generally best made in colours by means of a camel-hair brush, for a black-lead pencil cannot give the detail with the certainty and durability required.

A microscopical drawing should illustrate the description of the objects, and at the same time be so executed, that others who wish to repeat the observation may be led to observe the objects in the same manner. The general instructions given above are consequently not sufficient; we must also make a discriminating choice of the objects we intend to represent; the prettiest and rarest forms should not be sought for; the drawing should not be crowded with unessential details, or more introduced into it than it may reasonably be expected that another person might also see; the drawing should be a true copy of nature.

If we look at an object with the left eye, through the microscope standing vertically, lay upon the table at the side of it a sheet of paper, and look at it with the right eye, with the help of *double sight* we can bring the image of the object to rest upon the paper, and delineate it in this manner by merely following its contour. But this method, which, as we have already remarked, was employed by Hooke for the measurement of an object, is wearisome for the eye. Bauer used a similar method, placing a micrometer divided into squares in the eye-piece and drawing the object upon a piece of paper, upon which were formed squares corresponding in size to those of the micrometer, all the parts of the image found to be in the squares of the micrometer were then drawn in the corresponding squares upon the paper.

At the present time, various instruments are used for the delineation of objects. All are based upon the same idea, namely, a simultaneous reflection of the object or its image and of the paper, so that by help of the mirror the object or its image appears to rest upon

the paper. As it is more convenient to draw upon paper placed in a horizontal position than in a vertical one, the microscope is generally used in a horizontal direction. The farther the paper is from the eye-piece the larger the object will appear, for its image will seem to rest upon the paper, and its size will therefore be regulated by the distance of the surface upon which it is intercepted. It is therefore also necessary here to draw the object at a certain distance of vision of $0{\cdot}25^{m}$, and to place the scale, by which the object is to be measured, by the side of it. In relation to the choice of the magnifying powers employed in the delineation of different objects, we refer to the remarks at page 52.

Among the various forms of the apparatus which we will enumerate in the following part of this work, the most commonly used are Sömmering's mirror and Amici's perforated mirror (camera lucida). They may also be applied to the single microscope, when duly altered for the purpose.

Sömmering's Mirror consists of a round or oval polished steel plate of $\frac{1}{10}$th to $\frac{1}{5}$th of an inch in diameter, which is fixed upon a little rod, which can be moved backwards and forwards upon the eye-piece. In using the mirror there are two ways of placing it: either so that the image of the object may be reflected, whilst the paper is seen directly, or in such a manner that the paper is reflected, and the image of the object seen directly. In the former case, the surface of the mirror (upon the horizontal microscope) is directed obliquely upwards against the eye-lens at an angle of about 45°; if we look downwards, the image of the object is seen in the mirror; but the paper that lies below is also seen, and when we look, as it were, through the mirror at the same time, the image of the object will appear to rest upon the paper, and we can follow its contour with the pencil. In the latter case, on the contrary, the mirror is placed with its surface obliquely downwards against the paper, and, on viewing the image of the object in the microscope in a horizontal direction, the paper is reflected. As, in every case, distinctness of the image of the object is to be preferred to distinctness of the paper and of the hand engaged in drawing, the latter position should have the preference.

Some practice is required in order properly to use Sömmering's mirror, particularly because the image is inverted, so that the hand must move in a direction contrary to that of the image. This,

however, is not the case with *Amici's Perforated Mirror* (Pl. I. Fig. 14), which consists of a little circular polished steel plate, with a circular opening of about $\frac{1}{10}$th of an inch in diameter; the little mirror rests upon a moveable plate connected with the eye-piece, and turning obliquely downwards against the paper. To counteract the above-mentioned inversion, a prism is applied a little below the mirror. Here, likewise, the image of the object is seen directly through the opening in the mirror, which is placed before the middle of the eye-lens, whilst the paper and the hand are reflected. If this mirror is to be used with a perpendicular microscope, either the delineation must be made upon a vertical surface, or a prism must be applied for reflecting the horizontally inclined paper.

Instead of Sömmering's mirror, a very small prism may be used, as applied by Oberhäuser to his microscope. This camera lucida is also used with the horizontal microscope, and consists of an eye-piece provided with a prism in a joint, upon which a horizontal plate with a circular hole is securely fastened; under this the little prism is introduced. The observer, looking perpendicularly downwards, sees the paper through the hole in the plate at the same time that he watches the image of the object reflected by the prism. Amici's perforated mirror is preferable to this,—first, because the paper is reflected, and not the image of the object; next, because it can be applied to any sort of eye-piece, and easily turned aside when not required without shifting the eye-piece to continue the observation; lastly, the inclined position of the head when looking downwards is avoided, and the whole construction of the microscope, to which it is applied, is more advantageous.

Brunner applies to the vertical microscope a camera lucida, consisting of a prism, before which stands a perpendicular plate with a circular opening. The paper, on which the drawing is to be made, is laid before the microscope, and is seen immediately through the opening, whilst the image of the object is reflected. Besides this last defect, there is also this inconvenience connected with the use of this apparatus, that the paper must be laid before the microscope, by which the admission of light upon the reflecting mirror is obstructed.

Wollaston's camera lucida, the idea of which has been used in the three above mentioned, consists of a rectangular prism, whose hypothenuse turns obliquely towards the eye-piece, but is divided at

an angle of 135°, so that the prism becomes quadrilateral. The object is seen directly and horizontally, while the paper is at the same time reflected from one side to the other of the prism. Pritchard uses a quadrilateral prism with parallel surfaces, which is attached to the horizontal microscope; but since the observer must look downwards from above, the image of the object, and not the paper, is in this case also reflected.

When the camera lucida is being used, the eye must be kept in a steady position, and care must be taken that the light which falls upon the paper has about the same intensity as that by which the image of the object is illuminated in the field of view; for, in the contrary case, one of the parts will be seen less distinctly. By interposing the hand, we can diminish the light when it is too strong upon the paper. If the object be only weakly illuminated, it is at times advantageous to draw with white chalk upon black paper, or to draw upon transparent paper placed upon a black surface: paper of various colours may also be used.

To obtain very large drawings, images may be employed formed by the solar or oxyhydrogen microscope, of which we shall treat hereafter.

Lastly, we may mention that, in latter times, the Daguerreotype has been used in the delineation of microscopical objects; but it is only the single (solar) microscope that can be used, as only the rays from the object itself, and not from its image, can become fixed upon the silver plate. The attempts to etch the image fixed upon the plate, in order to obtain impressions of it, have not yet been perfectly successful. (Berres, Donné and Fourcault.)

e. *On the Preservation of Objects.*

Many objects only last for a short time, and must therefore be prepared afresh on each occasion of observing them. Some objects can indeed be preserved, not as microscopical preparations, but in larger fragments, of which such a preparation can be made. This applies to objects which can be preserved in a dry condition, in alcohol, turpentine—in short, in common preservative media. However, this method can only be applied where the structure maintains itself unchanged. When the object is rare or costly, or when it requires much time and pains to prepare it anew, or to illustrate its nature very distinctly, it will often be important

to be able to preserve the microscopical preparation unaltered, so that, without further inconvenience, it can at all times be brought under the microscope.

When the substance is only to be preserved for a few days, and exists in a fluid, either more of the same fluid may be added as soon as any evaporation is observed, or the whole glass-plate, on which the object rests, may be laid in a vessel containing the same fluid. If the object be at the same time covered with a thin glass plate, this is surrounded with a little circle of wax or oil to prevent evaporation. Yet the last method cannot always be used; for example, infusoria would in such circumstances die from want of air. It is thus better to preserve these in small test tubes, into which some vegetable is laid close to the glass, because the animalculæ like to find their way in that direction, for the sake of the light. When, with the exception of a little opening, the whole glass can be made dark, we may be certain of finding the animalculæ, which may be taken up with a small pipette or a finely pointed quill.

If the object, on the contrary, is to be preserved for a longer time, various other methods must be adopted. If it can exist in a dried state, it is enclosed between two glass-plates united with sealing wax. If it is also necessary to add a fluid on observing it, there must be an opening left between the glass plates, through which the fluid can be drawn in by capillarity. In this way many vegetable substances may be preserved, likewise bones, teeth, and hard bodies in general, which are not injured by being kept in a dried state. Most hard dry substances, also, bear preservation in varnish, Canada balsam, or gum-arabic, in which they are allowed to dry upon a glass plate; still the gum easily cracks, which interferes with the observation, or becomes loosened from the glass plate, so that the whole preparation may be lost, when it is not covered with a thin glass. It is less advantageous to keep the preparation in honey or in a syrup, because evaporation sometimes gives rise to the formation of crystals.

Some objects, which exist in a fluid, and which are only used for demonstration, are preserved by spreading a thin layer of them upon a glass plate, and letting it become rapidly dry. In this manner, for example, the globules of the blood and spermatozoa can be preserved. It is best to preserve the object in the same fluid in which it has been examined. The prepared object is then laid between two

glass plates, which are bound together with a thread and laid in a glass with the fluid in which they are to be kept. But as the glass plates are not closed at the edges, the preparation may easily fall out. It is also difficult to keep the preparations in order, when many of them are preserved in one and the same glass. Another mode of procedure has therefore been employed by closing the glass plates hermetically. A glass plate of larger size is chosen, which, with the exception of a little spot, is painted black; upon this spot the body is laid in a fluid, and it is then covered with a thin glass plate. The closing is effected by coating the edges of the thin glass plate with a drying varnish of copal or asphalte. But a loss of time is incurred by this method; the very thin glass plates are costly, and the preparations often suffer by changes of temperature.

I therefore use another method to preserve preparations hermetically closed. Thus, for instance, I take suitably-sized squares of plate-glass, all of equal size (one and a third inch by two inches). The object is prepared and is laid upon the middle of the glass plates, and then is covered with another glass plate, after the addition of only a small portion of a fluid. The covering plates must be so thin that the focal distance of the object-glass permits their interposition. If the object is to be viewed from the upper surface only, the thickness of the subjacent glass plate is immaterial. This also applies to the upper plate, when the object is only to be viewed with a low magnifying power. The glasses then are united with common black sealing-wax; but care must be taken not to use a wax which can be dissolved by the fluid in which the preparation is to be preserved. Thus it has happened that, in consequence of having used a perfumed wax in preparations that were kept in turpentine, I have found that the turpentine dissolved the odorous particles, and the preparation became muddy. The sealing of the glass plates requires some practice. All the four sides of the glasses, with the exception of a small opening, are first closed by letting the melting wax run down on the edges of the glasses, and pressing it fast upon them, so that a fine layer may insinuate itself between the glass plates; the edge is then rendered smooth by pressing it against a polished body, and the superfluous wax is cut away with a knife. Through the little reserved opening, the fluid in which the object is to be preserved is then introduced. The

glasses are then placed with that opening turned upwards, so that all the air-bubbles may rise and escape. Finally, the little aperture is closed.

The choice of the fluid in which the object is to be preserved, depends upon the fluid in which it is examined. I have found diluted alcohol, very diluted chromic acid, and especially turpentine, most serviceable; yet the last at times makes the object too transparent, and, as we have already observed, cannot be used when the object contains any greasy particles. Chromic acid, after the lapse of some time, may colour the objects too deeply; and alcohol becomes dilated by increase of temperature. The consequence of this is, that the wax bursts, the fluid evaporates, and the preparation is spoiled, if it be not watched. It is therefore advantageous with preparations preserved in diluted alcohol or chromic acid, to let a little air-bubble remain before the complete closure of the glasses. I have in my possession, hermetically closed preparations that have been preserved for several years in these fluids; and amongst them, those preserved in turpentine have been exposed, without injury, to very considerable changes of temperature.

If there be a fear of too strong pressure upon the superposed glass, we may beforehand lay a strip of thin paper or a hair along the edge of the subjacent plate; the paper or the hair is then concealed by the wax that has been introduced between the glasses. The expulsion of the air is often effected with some difficulty. The air-bubbles are in general pretty easily dispelled, and sometimes they may be removed by heat, if the preparation will bear a high temperature. But, on the whole, a small air-bell is not injurious when it has not fixed itself upon the preparation. I place a label between the glass plates, so that it only can be lost with the preparation itself. Finally, the edges of the glasses are painted black with a varnish, and do not require to be surrounded with a frame. Other persons have used as preservative fluids, oil, solutions of caustic potash, common salt, alum, chloride of calcium, corrosive sublimate, arsenic, and sugar; the last substance, however, easily enters into fermentation. Distilled water is objectionable, because a multitude of molecules are in the course of time developed in it, and disturb the observation. When the substance is very thick, a watch-glass covered with another watch-glass or a flat cover can be used; yet the observation may sometimes be disarranged by the

convexity of the glass; and this remark is also applicable to glass in which cavities are ground, and in which, further, the polish is not always perfect. To preserve objects of greater thickness, rings may be cut with a diamond from a cylindrical glass tube; these are then fastened upon a flat glass plate with some kind of cement, and protected with a round cover of the same size. Instead of common black sealing-wax, a thick composition of asphalte has been employed, which, however, easily becomes viscous with warmth. Damar resin, or copal, either alone or mixed with white lead or cinnabar, may likewise be used. A composition of wax and resin has also been recommended. Objects which are to be preserved in an acid (for example, hairs in sulphuric acid), must be enclosed in a medium which is impervious to the effects of the acid. Dry opaque bodies (for example, injected preparations), are cut in small pieces of suitable size, then fastened upon a flat piece of wood, or rather upon a flat glass plate, so that a Lieberkühn may be used for observing them. They are covered with a varnish, and protected against dust by a thin glass covering plate.

CHAPTER IV.

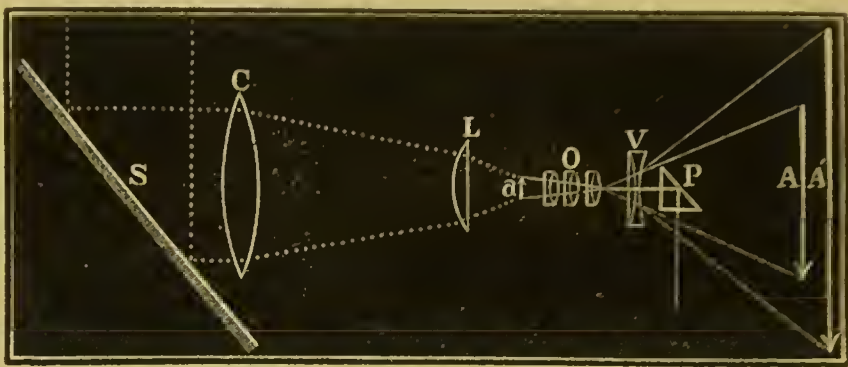
OF THE SOLAR, LAMP, OXYHYDROGEN, AND PHOTO-ELECTRIC MICROSCOPE.

All these microscopes so far agree, that, with the help of a lens, or a system of lenses, an image is formed in the same manner as with the object-glass of the dioptric compound microscope; but instead of this image being magnified and examined with an eye-piece, it is intercepted upon a screen. In mode of illumination however, they do not all agree, because, while the first-mentioned is illuminated by the light of the sun, artificial light is employed with the others. We have before seen that a magnified image of an object may be produced by bringing it into the interval between the single and double focal distance of a convex lens, and that the distance of the image from the lens and its magnitude are in direct proportion to the proximity of the object to the lens. The more distant, therefore, the screen, the larger, but at the same time the more indistinct and obscure, does the image thrown upon it become; and here, therefore, as well as with the length of the tube of the compound microscope, a limit must be set for the distance of the screen, if we wish to obtain a distinct image.

With the *solar microscope* (*Microscopium solare*) a moveable plane mirror S is placed outside of the window, to receive the direct rays of the sun. As only these rays can be used with this microscope, it is best that the window should look towards the south. From this mirror the rays are thrown upon a great bi-convex lens C, fixed in the window of the room, which must be elsewhere completely dark. The lens concentrates the rays in its focus; and to do this the more strongly another bi-convex or plano-convex lens, L, is employed. Both these lenses are adjusted to a conical tube, which is blackened in the inside. The object A is placed in the focus of the lens L, and is thus very strongly illuminated. The image A is then formed

by an object-piece; O, composed of three achromatic lenses, which may be of different strength, and is then thrown upon a screen

Fig. 18.



placed behind the instrument. If we wish to form the image upon another place, for example upon the floor or the ceiling of the room, a prism, P, is employed, by which the direction of the rays of the image is changed.

Lieberkühn was the inventor of the solar microscope (1738); but his instrument lacked an essential part, namely, the reflecting mirror, and he could therefore only use it during a short portion of the day, or only so long as the concentrating lens could be directed immediately against the sun. The reflecting mirror was added by Cuff, who at the same time made it moveable, which is necessary in order to maintain the illumination unchanged, and fix the image at one and the same spot,—for example, for the purpose of drawing it; for, as the earth gradually changes its position relatively to the sun, the position of the image is also changed, and we must therefore continually pursue it with the mirror. To render the movement of the mirror very accurate, a heliostat may be employed, which is so constructed that the mirror is moved by clock-work, and exactly follows the apparent motion of the sun. Instead of a mirror of glass, Euler used one of metal. Gleichen added (1768) the camera obscura to this microscope, for the purpose of delineating objects.

Charles Chevalier has made the lesser lens moveable in the conical tube, in order to vary the focus of the rays and diminish their strength. As with the compound microscope, this is of particular importance in the case of very transparent bodies. Objects may, however, become burnt by the strongly concentrated rays: living animals are killed by the heat, and humid objects become dry.

Martin first applied an achromatic object-lens; and subsequently to that period an object-piece of several lenses, screwed the one upon the other, has been used. The same object-piece may be used as with the compound microscope; yet it is possible that the lenses may also be injured by the strong heat, when the two glasses are connected achromatically with Canada balsam. In order to bring the rays to diverge still more, and thus to magnify the image, without its being necessary that the screen, on which the image is received, should be placed at a greater distance, Charles Chevalier has introduced a concave achromatic lens, V, behind the object-piece. As may be seen in Fig. 18, the image A', whose rays are made more divergent by the plano-concave lens V, is larger than the image A, only formed with the object-piece O.

The surface on which the image is received is either the wall in the room, when it is white and even, or a common wooden frame, such as that of a mirror, in which a sheet of white paper has been spread out. The image may then be delineated by the observer placing himself behind the frame and following its contour on the back of the paper. However, as this gives way whilst delineating, it is better to receive the image upon a glass plate, the back surface of which is covered with the paper. The wall must not be too far from the object-glass, especially when the image is being drawn, because the illumination then becomes fainter and the contours less distinct.

When the solar microscope is being used, the direct rays of the sun are made to fall upon the mirror, and are concentrated by means of the two large lenses we have mentioned. The object is placed upon a glass plate, in a clamp fastened upon the conical tube which supports the lenses. The glass plate is placed perpendicularly, and the object must be so fastened upon it that it does not sink; it is therefore best to lay it between two glass plates. It is then brought into the focus of the rays, or, to avoid too great heat, fixed at a little distance from it. It must at the same time be placed a little beyond the focus of the object-piece, and this position can be obtained, as with the compound microscope, either by moving the stage or the object-piece. The above remarks apply, however, to the solar microscope when used with transparent bodies. Lieberkühn's mirror must be employed with opaque bodies. Brewster has also here applied lenses in connection with a fluid, to produce an achromatic object-glass.

The object is immersed in the fluid, and brought into the focus of the lens. Goring has employed a concave mirror instead of the object-glass, and has also used a compound microscope as an object-piece.

As the object cannot at all times be illuminated by the direct rays of the sun, the elder Adams (1771) substituted a lamp for the solar light, whilst the optical part of this instrument, called the *Lamp Microscope*, remained the same as in the solar microscope. Adams likewise applied the camera obscura. However, this microscope has fallen out of use, because the light is too weak for high magnifying powers. The *Oxyhydrogen Microscope* is still in use. The optical part here is also constructed as in the solar microscope; the reflecting mirror can alone be dispensed with. The illumination takes place with the Drummond light, by the combustion of oxygen and hydrogen upon a lime ball, introduced into a small quadrangular box, into which these gases are admitted from two gasometers. Caution must be used in mixing and lighting the gases. After the light has been concentrated by a lens, and thrown upon the object, the image is formed by the object-piece, and received upon a screen. Still stronger light may be obtained by a stream of electricity, evolved from a voltaic battery, and allowed to pass between two charcoal points. The optical parts of this *Photo-electric Microscope* are the same as those above described.

All these microscopes are not applicable to special investigations, but they may be used in popular and entertaining exhibitions before a large circle of spectators. They are commonly found in the hands of travelling artists, who often dazzle the public with the colossal forms which they are able to throw upon a wall, whilst the enlargement takes place at the cost of distinctness. Besides, as before mentioned, the choice of objects is considerably limited by the circumstance, that only a proportionally small number bear the heat. The various pieces of apparatus are also rather costly, and take up much room, and the preparation of the gases requires considerable sacrifice of time.

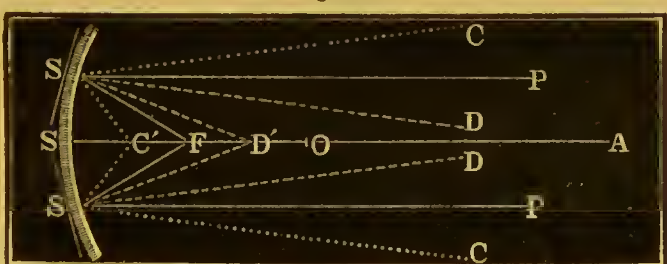
CHAPTER V.

THE CATOPTRIC COMPOUND MICROSCOPE.

THIS microscope differs so far from the dioptric compound microscope, that the object-piece, which in the latter is composed of lenses, is supplied in the former by a concave mirror, by which a magnified image of the object is produced. This image, again, is viewed with the same eye-piece, as in the dioptric compound microscope. To understand the operation of the concave mirror, we will call to mind some principles of catoptrics, or the doctrine of reflection of rays of light.

When a ray of light falls upon the smooth polished surface of an opaque body, its continuance in the same direction is interrupted, it is thrown back by the reflecting body, which is called a *mirror*. If the rays fall perpendicularly upon it, their reflection is in the same direction; if, on the contrary, they fall obliquely upon the mirror, reflection takes place at an angle formed with the perpendicular to the surface, equal to the angle which they make with the same perpendicular when they fall on the mirror; or, in other words, the angle of reflection is equal to the angle of incidence. This is the law of all reflecting surfaces, both plane and curved; for, in the last case, the size of the angle is determined by the perpendicular which accords with the radius of the curve to which the tangent is perpendicular. If we suppose that the rays P S, A S,

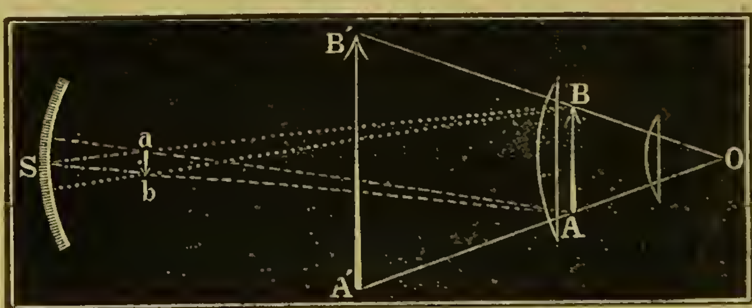
Fig. 19.



P S, parallel with the radius O S, fall upon a concave speculum, the ray A S will be reflected in the same perpendicular direction

as that in which it fell. The rays P S, P S, are reflected at an angle which is equal to the angle of incidence formed by the tangents perpendicular to the radii O S, O S; they coincide in a point which lies between the concave surface and its centre O. This point, F, in the radius to which parallel rays are reflected, is called the *focus of the speculum.* It is situated in the middle of the radius of the curvature, and its distance from the mirror is the *focal distance of the speculum.* If the rays D S, D S, falling upon a concave speculum, are divergent, they are indeed reflected to a point D′, between the mirror and the centre; but this point is at a greater distance from the mirror than the focus of the parallel rays. The nearer the luminous point approaches the centre of curvature, the nearer does the point of convergence advance towards it; and when the luminous point is precisely in the centre of curvature, this centre coincides with the point of convergence. If the luminous point is between the centre and the focus, the rays again converge upon the other side of the centre, they are reflected as parallel rays when they proceed from the focus. If, finally, the converging rays C S, C S, impinge upon a concave speculum, they are reflected and converge in a point C′, between the speculum and the focus, and their condition becomes the same as that of parallel rays, when they come from a very considerable distance. Here we find a complete analogy with the refraction of rays of light (See Fig. 7, p. 71), and the analogy is also apparent in the manner in which the concave mirror is used to produce an enlarged image of an object. If, for instance, the object *a b* is placed a little beyond the focus, a ray, *a* S, proceeding from *a*, will be reflected at an angle,

Fig. 20.



a S b, to a point A, and in the same manner the ray proceeding from the point *b* to a point B, or by the help of the concave speculum, the image A B of the object *a b* is formed, which image is con-

siderably larger than the object, and which, at the same time is inverted (See Fig. 14, p. 20). This image is now viewed with the two lenses of the eye-piece, and is seen magnified in the direction O A and O B, as A′ B′ (See Fig. 16, p. 26).

A microscope constructed in this manner, is called a *reflecting microscope* (*Microscopium Catadioptricum*). Newton (1679), first suggested the idea of its construction; but Baker appears first to have carried it out. After him followed Smith (1738), and W. Herschel (1774); in later times Amici has improved the apparatus, and Doppler (1815) has again recommended the mirrors with ellipsoidal curvature, prepared by Amici.

The concave speculum is made of metal,—silver, or a composition of silver, copper, and tin, or of platina. A concave speculum of glass would not give a pure image, because the reflection takes place from both surfaces of it. According as the curvature of the speculum is greater or less, the image becomes larger or smaller; and, as with convex lenses, the intensity of the light and the magnitude of the field of view decrease, according to the magnifying power, or to the greater curvature of the mirror. The magnifying power of the concave speculum is learned by dividing the distance of distinct vision by the focal distance.

The remaining portion of the reflecting microscope is, on the whole, exactly the same as in the dioptric compound microscope. Instead of placing the object in a vertical position directly before the mirror, and in the same tube, Amici places a plane metallic mirror obliquely before the concave speculum. Upon this the object, which is placed horizontally upon the stage, is reflected. The object is therefore placed outside of the tube, and can be applied more conveniently. But with this double reflection, there is a loss in the intensity of illumination, partly also because the plane mirror intercepts a portion of the rays of light from the concave speculum. On account of the lesser curvature of his concave specula, Amici could only magnify objects very strongly by using powerful eye-pieces, which again limited the field of view, and caused loss in the light and distinctness of the image. Goring and Cuthbert therefore increased the curvature of the concave speculum. Their strongest had a focal distance of three-tenths of an inch, but this gave rise to the inconvenience that the object must be brought so near the mirror that it came into the tube of the microscope, and the light became very weak.

The reflecting microscope only maintained its celebrity for a short time. Great results were expected from the circumstance that chromatic aberration could be removed, because the rays of light were only reflected, and not refracted, as in glass lenses; but this happened particularly to be at a time when the art of joining glass lenses achromatically was unknown. At a later date, it regained its reputation through the efforts of Amici. Even when the chromatic aberration can be superseded, spherical aberration always remains, for it is as difficult to grind concave mirrors with perfection as to grind lenses. Besides this, the mirrors easily lose their lustre, so that the whole microscope becomes spoiled. Objects cannot be very strongly magnified by this instrument without the use of powerful eye-pieces; and if, as before mentioned, we wish to avoid the use of these, and apply powerful concave mirrors, the object becomes difficult to manipulate, because it approaches the tube of the microscope too closely, or rather must be placed in it. It is also of less value than the dioptric compound microscope in the examination of opaque bodies. It is possible that the expense of the reflecting microscope may be lessened by preparing the concave specula by the Voltatype process; but it is hardly probable that its use will ever become so general as that of the dioptric compound microscope.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1.—A *cylindrical lens,* with a diaphragm *a,* and with surfaces of equal curvature. P. 15.

Fig. 2.—Section of a *doublet* of Charles Chevalier ; *a* and *b,* the two lenses which have their plane surfaces turned downwards towards the object. P. 16.

Fig. 3.—Section of *Wilson's lens ;* the lenses, with their convexities directed towards each other, are inclosed in a brass tube with a diaphragm *a.* P. 17.

Fig. 4.—Section of an *object-piece,* consisting of three achromatic lenses screwed to each other; it is fixed by means of two projections *a a,* which are received into two slits in the tube of the microscope. P. 25.

Fig. 5.—Section of a *double eye-piece; a,* the eye-lens; *b,* the field-glass; *c,* the diaphragm. P. 27.

Fig. 6.—Moveable *stage;* the upper plate *a a* is moved backwards and forwards by means of the screw *d d*; the plate is inserted in the frame *b b,* which is moved from one side to the other by the screw *e*; the lower plate *c c* is fixed ; by turning the screws *d* and *e* at the same time, the plates can be moved in a diagonal direction ; *f,* aperture in the stage for the passage of the light from below. P. 33.

Fig. 7.—Section of *Lieberkühn's mirror ; a a,* the concave mirror, which receives the rays of light from the reflecting mirror, and throws them upon the object *b,* lying upon a glass-plate *c,* which latter rests upon the stage. The object-piece is fixed about the centre of the mirror. P. 35.

Fig. 8.—A moveable *diaphragm,* with apertures of various sizes. P. 36.

Fig. 9.—*Dujardin's illuminating apparatus;* the rays of light, the quantity of which can be regulated by the aperture of the screen *a a,* first fall upon the prism *b,* and are then concentrated by three lenses, connected in a tube, and placed under the stage, before they are thrown upon the object *c,* which rests upon a glass-plate *d.* P. 37.

Fig. 10.—*Valentin's double knife; a* bolt or screw, for fixing the blades at various distances from each other. P. 38.

Fig. 11.—*Schiek's compressorium;* by means of the screw *a*, one end of the balancing beam *b*, which moves round the pin *c*, is raised; thus the other bifurcated end *d* is pressed down together with the ring *e*, which balances within it, and in which a plane glass is fixed; the object-slide is fastened in the brass plate *f* underneath. P. 40.

Fig. 12.—The *screw micrometer;* in the little square flat box *aa*, which is screwed fast upon the stage, a brass bolt *bb* is moved by the micrometer screw *c* from one side to the other, and its movement in one direction is determined by the pin *d*, which perforates the opposite side of the box. Upon the brass bolt *bb* the larger and thiner plate *ee* is screwed; on this again rests a frame *ff*, in which the plate *g* is fixed for the purpose of being moved backwards and forwards by the screw *h*. These different plates, fixed to each other, are moved from one side to the other by the micrometer screw *c*, the head of which, *i*, is divided into a hundred equal parts; the single revolutions are marked by the help of the plate *k*, their separate parts by comparing them with the zero of the vernier *l*, ten parts of which are equal to nine parts of the screw-head. The head *i* is loose, and before the measurement is made, the zero must be fixed opposite to the zero of the vernier, but is then made fast by the screw *m*; *n* is the opening in the plates for the passage of the light from below. A rotatory disc may be fastened upon the plate *g*. P. 67.

Fig. 13.—Two *glass micrometers.* A, a loose glass plate divided into squares; B represents a millimetre divided into a hundred portions upon a glass plate; it is fastened in a brass slide. P. 70.

Fig. 14.—*Amici's perforated mirror.* A seen in front, B seen from the side; upon the plate *a*, placed before the eye-piece *b*, a steel mirror *c* is fixed in an oblique direction; this mirror has a circular aperture in the centre, through which the object is directly viewed, whilst the paper and the hand which delineates, are reflected; the prism *d* serves to counteract the confusion occasioned by the image being inverted. P. 83.

PLATE II.

MODELS OF MICROSCOPES NOW MOST COMMONLY IN USE.

Fig. 1.—*Single microscope of Charles Chevalier; a*, a pillar screwed fast in the box, in which the microscope is kept; upon it the rod *b*, bearing a doublet *c* in a ring, is moved up and down by a rack and pinion, having a handle *d*. Upon the fixed stage *e* there are two clamps *f f*; under it is the diaphragm *g*, and the reflecting mirror *h*, which is capable of being moved in all directions.

Fig. 2.—*Compound microscope of Charles Chevalier; a*, a stand screwed fast in the box of the microscope, and bearing upon the cross piece *b*, the perpendicular square pillar *c*, which is fixed to the stand by a pin *d*. This pillar lower down supports the reflecting mirror *e*; above this is the diaphragm *f*, which can be turned aside, when not required for use. Above this again is the stage *g*, with two clamps *hh*; it is moved partly by a rack and pinion, placed at the back of the pillar, whose handle is at *i*, partly by means of a finer screw *k*. Upon the foremost end of the transverse piece *b*, is placed the optical portion of the

microscope, that is the tube with the prism *l* in the joint (which can be removed when the instrument is placed vertically), the object-piece *m* and the eye-piece *n*. The tube can be lengthened at *o*, and the whole optical portion can be detached by unfastening a pin, which is held by the peg *p*. The whole quadrangular pillar, with the apparatus resting upon it, can be turned round at *q* and *r*, so that the stage and the reflecting mirror become placed above the tube, together with the object-glass and eye-piece.

Fig. 3.—*Compound microscope of Schiek and Plössl; a*, the stand, resting upon a tripod, under which adjusting screws can be placed; it supports the three-cornered pillar *b*, upon which the tube of the microscope *c*, with the eye-piece *d* and the object-piece *e*, is moved up and down with a rack and a fine screw, the head of which is seen at *f*. The pillar and the tube can be turned directly against the light by being rotated round the joint *g*; the pillar bears, besides, the stage *h*, with the diaphragm *i* and the reflecting mirror *k*.

Fig. 4.—*Compound microscope of Oberhäuser; a*, a hollow cylinder, resting upon a heavy foot *b*; in it is placed the reflecting mirror *c*, moveable by the screw *d*. Upon the cylinder rests the stage *e*, which can be turned round its axis, and is furnished with different small cylinders *f*, to admit of applying Selligue's lens, pincers, etc. Under the stage is the diaphragm *g*. One end of the stage supports upon a prolongation the pillar *h*, which consists of a solid cylinder between two hollow cylinders, by the assistance of which a lateral movement can be produced on turning the transverse piece *i*, together with the optical portion of the microscope, outwards from the stage; while by means of the screw *k*, a fine adjustment of focus may be effected. In the cylinder *l*, the tube *m* is moved with the eye-piece *n*, and the object-piece *o*, up and down, by using either the resistance of friction, or a rack and fine screw; the tube consists of several portions, which can slide down into each other.

Fig. 5.—A smaller model of *a compound microscope of Fraunhofer; a, b, c, d*, as in Fig. 4; *e*, the immoveable stage; *f*, the handle for the rack and pinion, which sets in motion the tube *g* with the eye-piece *h*, and the object-piece *i*, in the cylinder *k*. Selligue's lens *l* may also be applied to these forms of microscopes.

Fig. 6.—*Solar microscope of Charles Chevalier; aa*, a wooden frame fastened in the window of the room, and upon which the brass plate *bb* is made fast with the screws *cc*. The reflecting mirror *d* can, by means of the screws *ee*, be moved in various directions, in order to follow the apparent motion of the sun. In the brass plate *bb* a conical brass tube is fastened, having in its broader end *f* the larger concentrating lens for the purpose of collecting the solar rays from the mirror. In the smaller end, which contains a cylindrical tube, the tube *g*, supporting the lesser concentrating lens, moves backwards and forwards, by means of the rack and pinion *h*, in order to moderate the quantity of the rays of light upon the object, which rests upon the plate *i*, and is held fixed between the plates *kk*, united by four spiral springs. The optical portion of the instrument is formed by the object-piece *l*, and the concave lens *m*, which are fixed upon the vertical piece *n*, and may be brought to a greater or lesser distance from the object by the help of a rack and pinion with a handle at *o*.

Fig. 7.—*Catoptric microscope of Amici*, with a modification by Charles Cheva-

lier; *a*, a tube containing the concave mirror *b*, and the plane mirror or prism *c*; *d* is a hollow cylinder, which stands upon the stage, and upon which the object that is applied can be moved either further from or nearer to the aperture *e*, through which the light falls, and where a Lieberkühn mirror is placed, for the illumination of opaque bodies. The rest of the microscope is exactly similar to the model Fig. 2, with the exception of the object-piece and the prism in the joint.

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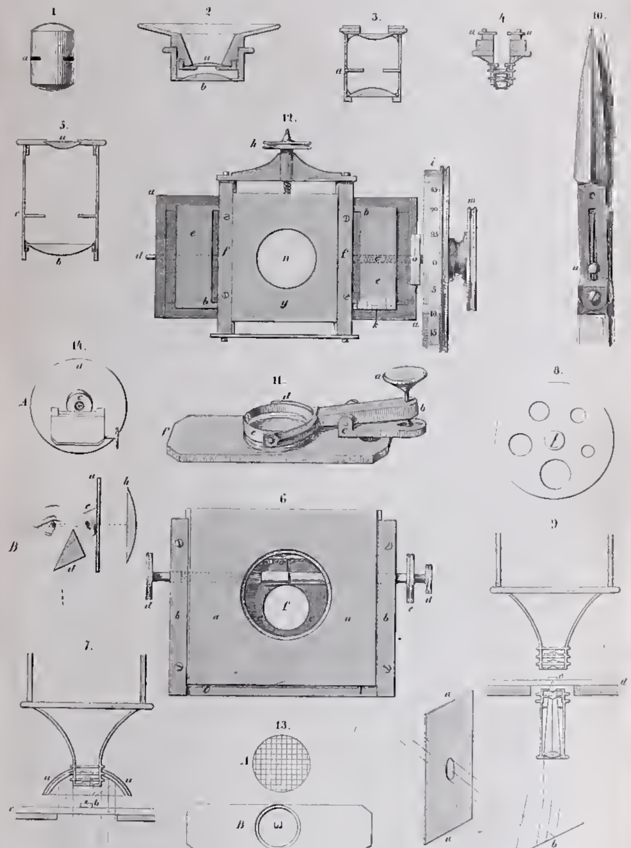
Tab. I.



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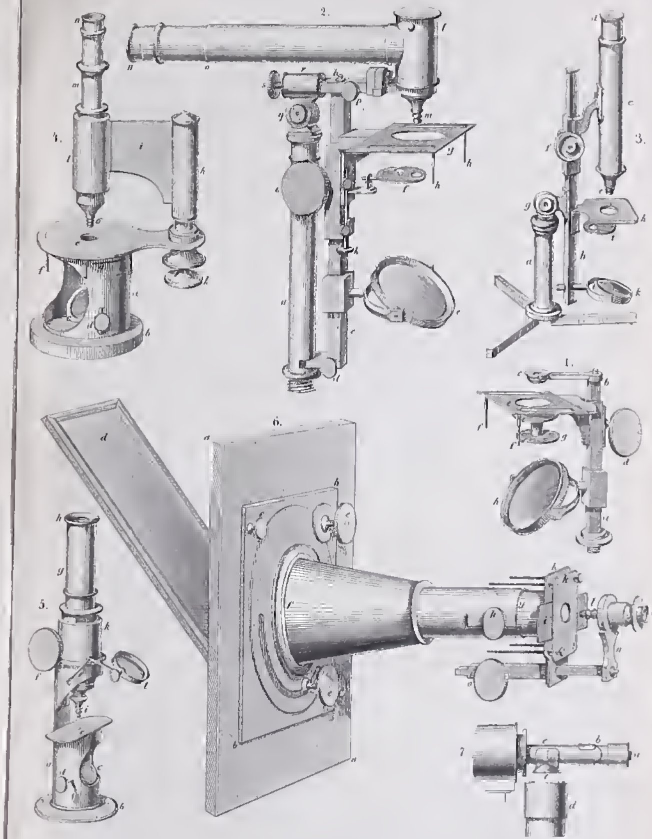

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BEGS to call the attention of Observers with the Microscope to his improved Instruments, a Catalogue of which may be had upon application.

Among the various advancements A. R. has effected, is the extreme enlargement of the aperture of the MICROSCOPE OBJECT GLASS, which is its real effective improvement; also an Achromatic Condenser of Light for the Microscope, on a new combination of principles, for the illumination of transparent objects, adapted for use, with the several Object Glasses from $\frac{1}{2}$ an inch to $\frac{1}{12}$ of an inch focal length inclusive.

The object of this arrangement is to develop the defining powers of Object Glasses, and, by a peculiar adjustment, to adapt the illumination to the nature of the object and to the mode of mounting, whether dry or in fluid, or in Canada Balsam, so as to admit a greater quantity of light with less glare, and, in consequence, to give a more distinct image with less fatigue to the eye. The Microscrope Stand, or mechanical part, has also been arranged to ensure freedom from tremor and afford facility in use.

A. R. also begs to announce, that from a laborious practical investigation of the construction and manufacture of the Achromatic Astronomical Telescope, he has arranged a new process for their production, which ensures the perfection of that important instrument; also, that in Terrestrial and Naval Telescopes, the contact surfaces of the Object Glasses are united by a permanently transparent cement, which obviates the loss of light by reflections, and prevents that decomposition of the glass which generally occurs in Marine Telescopes.

Since the invention of those prospectively useful arts, the Calotype and the Daguerreotype, A. R. has investigated the forms of lenses necessary to give just representations of objects, and has succeeded in giving great intensity to the image with fine and correct definition, both at the centre and margin of the picture; also the visual and chemically acting foci are made to coincide.

GREAT EXHIBITION.

The Council Medal was awarded to ANDREW ROSS, for Great Improvements in the Microscope, and construction of Telescopes.

Jurors' Report, p. 274.

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